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REPORT

ON

DESIGN CONSIDERATIONS

FOR A

HEAT PUMPED ICE FIELD

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Suite 200, 2 Sheppard Avenue East, Toronto, Ontario M2N 5Y7 • (416) 226-6565

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EXECUTIVE SUMMARY

1. General

This study concerns a quest to harness the abundance of warmth in the Canadian summer and the abundance of cold in the Canadian winter and to time cycle these surpluses to reduce the cost of heating and cooling buildings.

The scientific community has labelled this concept "seasonal storage". It has been the objective of an international society, for some years, to find a cost effective way to achieve this goal. Until now, however, seasonal storage has been an academic exercise, since no viable solution has been found to appeal to the building industry.

This study is just the most recent of many but it provides the potential for using seasonal storage in a way which not only saves energy but also reduces capital cost.

2. Outline of the System

The concept involves an all-electric heating and cooling plant for buildings. The heating for the building is provided by the freezing of a saturated soil mass located under the parking lot. By the end of the heating season there will be enough ice generated to provide for summer cooling.

The saturated soil mass will be interspersed with 1/2 inch diameter polyethylene tubing at approximately two foot centres horizontally and vertically. Methanol will be recirculated between this tubing system and an electric heat pump chiller located in the building. Water from the condenser of the heat pump will be circulated at temperatures as high as 110F to heating coils in the building. The heating of the building is thus accomplished by freezing the water in the "ice field".

The cooling is even more easily accomplished by recirculating the methanol directly between the tubing system and the building cooling coils. The building is then cooled by the melting of the ice.

Such a heating/cooling concept can be very efficient. Even though two thirds of source energy may be wasted in electric generation, the heat pump can recoup this with an expected average winter coefficient of performance of 4.4. Hence, the heat pump requires $\frac{1}{0.33 \times 4.4}$

or 0.68 units of source energy for each unit of heat, while fossil fired heating generation requires $\frac{1}{0.7 \text{ (seasonal efficiency)}}$

or 1.43 units of source energy. This is only part of the efficiency story because, once the ice has been generated to fulfill the heating function it is a free source of cooling.

The study will show that the cost of heating and cooling a building can be from 35% to 65% less than conventional depending on the detailing of the heat pump and storage systems.

3. The Building Prototype

The new Oshawa Administration Office for General Motors was chosen for the study.

This has been designed as a low energy building. It features a tight, well insulated, enclosure together with a low temperature air supply system backed up with diurnal (day by day) ice storage. This HVAC concept was chosen after careful checking by the designers and two mechanical contractors and installed only after it was found to be less expensive than a convention system in both initial and energy cost.

The excellent design features of this building offered a challenge to any alternative concept.

4. The Seasonal Storage

The ice field was designed, first to satisfy the entire summer cooling load (full storage) and, secondly to supplement the heat pump, acting as a summer chiller, (partial storage).

The full storage field required up to four times the area and cost of partial storage.

Each concept, full and partial, was configured in three ways. One, a bulk fill or "bathtub" type involved an excavation of up to 22 feet with successive layers of tubing and backfill. Since this generated concerns for parking stability, a second concept was studied which consisted of 30 inch "trenches" with 48 inch solid piers between. A third concept, "vertical", consisted of 250 ft. deep holes, 5 inches in diameter, each containing a U bend of 1 1/4" tubing backfilled with concrete grout. This offered the least potential for heaving and subsidence of the parking lot platform.

Protection against heaving and subsidence was provided in the first two concepts by a 2 foot layer of fill for water expansion above the field and a one foot layer of drained gravel above the expansion fill and below the asphalt.

5. Energy

Hour by hour energy simulations, using the Meriwether program, yielded the following costs:

	Seasonal Storage		Diurnal Storage
Item	Full	Partial	
	¢/sf/yr	¢/sf/yr	¢/sf /yr
Base electric load	54.1	54.1	54.1
Heating/cooling	5.8	11.4	15.9
Total	59.9	65.5	70.0

6. Capital Cost

This was based on estimates (made from sketch plans) by a number of contractors including Sayers & Assocs. Ltd. (the mechanical contractor on the job), Ellis Don Ltd. (the general contractors on the job), Petrex Ltd. (a successful Toronto excavating contractor) ar ' Ainsworth Electric.

The results are as follows:

	$ - Initial Cost of Heating/Cooling		
	Seasonal Storage		Diurnal Storage
	Full	Partial	
Diurnal			1,066,000
Bathtub	1,011,059	657,087	
Trenched	1,252,569	751,456	
Vertical	1,968,035	976,360	

Water Furnace Ltd. was also solicited for an estimate on the cost of a comparable ground source heat pump system. Their initial cost, at $1,780,000 compared with full seasonal storage while their energy cost compared with partial seasonal storage.

7. Imperial vs SI Units

In deference to those in the construction industry to whom this study should be targetted and, also, to suit the American energy programs, Meriwether and Loadshaper, this report has been couched in Imperial units.

8. Where to From Here?

This study holds great expectations along with concerns for the parking surface stability, noted above. Some recommendations are included in the report for low cost prototype field checks to assess the degree of liability for these problems and to prepare solutions.

1. OBJECTIVE

This study has been undertaken to determine if a seasonal heating and cooling storage system can be conceived in an economically viable way in order to reduce the energy cost of buildings.

Efforts to attain this goal have been made in the past. A society known as the "International Council on Seasonal Thermal Storage" has been meeting annually for a number of years in the hope of finding solutions. At Provident House in King City, Ontario, an attempt was made to capture enough solar heat in the summer to heat the residence through the winter.

"Project ice cube" in Quebec City, was another Canadian attempt at seasonal storage. Its objective was to build enough ice naturally in the winter to cool a building all summer.

Princeton University made an effort with a snow blower, operating within an inflated structure, to capture the winter's cold in useful quantities for summer cooling.

In all cases these projects have failed to provide all the required heating or cooling in an economic manner.

It is hoped that this study will reveal a concept for overcoming both problems. If so, it will be a world first.

2. BACKGROUND

The potential for seasonal storage appeared unlikely until Professor Ed Francis of Illinois State University delivered a technical paper to ASHRAE in 1981.

At this time he described a small buried ice storage which he had tested with the help of technology supplied by Calvin MacCracken and funds provided by the United States Department of Energy.

Francis proved that a saturated soil mass could be frozen during winter and melted the following summer without subsidence or heaving of the ground surface and with predictable losses to surrounding ground.

Although no attempt was made to suggest an economic return, the accurate measurement of results and minimal underground losses implied that such an ice field could be sized for seasonal storage and located under a parking lot to preserve valuable land area.

The idea then dawned that a viable seasonal storage in Canadian climate could, at last, be within sight.

The storage could be frozen with a glycol fan coil unit standing at the corner of the parking lot. The chilled glycol, circulating within the frozen mass under the parking surface, could then be diverted through HVAC cooling coils in the building for summer air conditioning.

At first, it seemed reasonable to combine the cool storage with an unrelated heating system. But, later, it became more logical to supplant the heating boiler in the building with an electric heat pump. The heat pump could then be a major influence in freezing the soil mass during winter and then become an assist for providing cooling during the summer. The heat pump would be less than 40% of

the size of a conventional chiller. It would operate economically at essentially full load during summer while producing heat at a COP above 4.0 in the winter. In other words, the heating could be accomplished at a cost below any available alternative, while much of the cooling could be provided "free" from the ice frozen from the previous winter's heating requirement.

If a reasonable first cost could be proven, the ice field concept would aspire to fulfill Ontario Hydro's objective of electric demand avoidance while providing building owners with a reliable heating/cooling system of remarkably low energy cost.

Accordingly, an approach was made to Ontario Hydro through Mr. Richard Booth, the chief architect, and Mr. P.R. Icely of the Energy Management Branch. Financing was eventually arranged through the courtesy of Ontario Hydro and Mr. R. Wiggin of the Department of Energy Mines and Resources.

3. LIMITATIONS

The expansion characteristics of frozen ground water make it undesirable to locate an ice field under a building.

Yet, the volume required for seasonal ice storage is large and the cost of serviced land is high - up to $25/sq.ft. in suburban areas.

The ice field should, most logically, be located under a parking lot in order to minimize the cost of property associated with the ice storage.

The volume required will limit application to sites where there are large properties or for commercial ventures locating along the perimeter of urban areas where outside parking is typically employed. Some care should be exercised to plan ahead so that building expansion and elevated parking structures do not have to be located over the ice field.

Fortunately, this is not a serious limitation. Fifty per cent or more of future construction sites will have surplus land or outside parking.

4. CALCULATION OF HEATING AND COOLING LOADS

An accurate analysis of energy requirements is not possible with existing computer programs. The ice field concept is unique since energy input to the heat pump depends upon the thickness of ice through which heat must be drawn.

This can vary on a day to day basis from 0 to 12 inches. As the ice radius increases, the glycol temperature must drop from 31F to less than 25F in order to salvage heat from the freezing process. The condensing temperature of the heat pump is also a weather variable since the heating coils in the building require water rising to 110F for maximum output. As the evaporator and condensing temperature vary to suit ice radius and heat output, the energy required to drive the heat pump can vary from 0.8 kW/ton to 1.5 kW/ton. Hence an accurate energy program would need to monitor ice radius as well as heat output to model energy use. This would require a special set of algorithms to simulate the rate of heat flux in the ice field. This can be developed for future use if the ice field concept becomes popular. Meanwhile, for this analysis, an estimate of average energy ratios were made to suit each month of operation.

Program Selection

The Meriwether series of energy analysis programs has been used to ensure that the program would have maximum acceptability to the federal government. In addition, Mr. Ross Meriwether, himself, has been retained as the programmer in the hope of achieving the most accurate possible result with the data available.

Building Prototype

The building chosen for analysis is the new administration office presently being completed for General Motors Canada on a site at the east end of Oshawa, Ontario.

The building is equipped with a diurnal ice storage system and a low temperature supply air system. During concept analysis these concepts were proven to be lower in initial cost than a conventional system by two prominent mechanical contractors. It was also shown to be lower in energy cost with the LOADSHAPER program. Thus, optimized, the HVAC system represented an appropriate challenge for the seasonal storage concept.

The General Motors office is a five storey building with the floor plan shown in Figure 1. Zones were ascribed, where indicated, to facilitate energy analysis.

The total floor area is 264,200 square feet.

Operating schedules were assigned as follows:

Fans	7 am to 9 pm on workdays
Lights	7 am to 9 pm on workdays (10% on at other times)
Electronic energy	8 am to 5 pm on workdays (50% on at other times)
Outside Air	8 am to 5 pm

Electrical inputs were as follows:

Lights	1 1/2 Watts/sq.ft.
Electronic (average)	1/2 Watts/sq.ft.
Central Fans	0.53 Watts/sq.ft. (for maximum CFM)
Air Terminal Fans	0.25 Watts/sq.ft.

Thermal characteristics were as follows:-

Roof	R20
Walls	R20
Glass	R3
Glass shading coefficient	0.4

The number of occupants was assessed at 1450 persons. A minimum of 20 CFM of outside air per person will be supplied during working hours. More outside air will be used through an economizer cycle at ambient temperatures below 70F to the extent that this will reduce energy.

Program Characteristics

Controls are provided to hold the space temperature at 74F during working hours. During unoccupied periods the temperature may stray upwards or downwards by 5F. When a boundary temperature is reached the fans and other apparatus will operate to maintain the boundary.

Loads required to re-establish temperature equilibrium in the morning are spread over seven hours after the 74F temperature is established. A space storage value of 25 Btu/sq.ft./F was used in the program. Thirty per cent of the light heat is assumed to be absorbed by the false ceiling.

Air supply at the fan discharge will be 45F. Air terminals will shut off against flow when thermostatically required but will be programmed to have 10% air leakage. Terminals will have "side pocket" fans which will operate when primary airflow drops to 40%.

Weather Profile

The weather program is a Version #707, provided by Meriwether and keyed for Toronto weather.

This is tabulated in Appendix D.

Program Outputs

The program was run to determine the maximum hourly heating and cooling loads as well as the annual heating and cooling.

Initial runs were made for continuous operation of the HVAC systems in order to ascertain the natural heating and cooling peaks.

Later, the program was rerun, as it might be in real life, with fans cycled on a 5F boundary limit. This reduced the annual heating and cooling requirements, although pick up loads developed which exceeded the former hourly peaks. Recognizing that these could be "smoothed" with occasional early equipment startup, the following loads were determined as representative of the way the system could best operate.

	Heating	Cooling
Max.Hourly	2.4 million Btu	8.4 million Btu (697 tons)
Annual	1,209 MMBTU	5900 million Btu (491,576 ton hours)

5. COMPARISON OF HEATING AND COOLING LOADS

A problem with the ice field concept appears to be that annual heating and cooling requirements are no longer close to equal.

Undoubtedly, less insulated buildings will be more equal than the GM building in heating/cooling tradeoff. However, the load discrepancy will be accepted as a challenge.

The discrepancy between annual heating and cooling energy is too large to be overcome with adjustment of the ventilation ratio. What will be needed, in addition to the heat pump, to freeze up the field, will be a glycol cooler accessory. A small one may suffice for partial seasonal storage, but a large one will be required for the full storage case.

The heat pump adds its own work energy to heat withdrawn from the ice field. In the maximum case, when the heat pump is operating with 25F glycol and 110F condensing temperature, the ratio is approximately 30% motor input and 70% withdrawal from the ice field.

Thus only 1209 x 0.7 or 846 MM BTU/yr. will be needed for ice **making** while 5900 MMBTU/yr of ice **melting** must take place to provide cooling.

The case for partial seasonal storage provides a better heating/cooling match.

Monthly heating and cooling loads are compared graphically in Figure #2.

6. THE CASE FOR PARTIAL SEASONAL STORAGE

To this point the study has envisaged a concept of "full storage" wherein a heat pump would deliver heat all winter by freezing up the ice field. The heat pump would then be idle in the summer while the ice field provided total cooling.

A more cost effective concept might be a "partial storage" where the heat pump could also operate during the summer to provide some cooling. Although using more energy, this concept would reduce the initial size and cost of the ice field.

A typical screw type glycol chiller operates in accordance with the table shown in Figure 3.

If this unit were used for the heat pump it would have 262 tons capacity as a summer chiller operating at 38F glycol and 95F condensing water. The Meriwether program calculated the reduction in the size of the ice field if the chiller was used to accomplish the first 262 tons of cooling. The results were as follows:-

Annual Cooling Energy Summary:

From 262 ton chiller	4763 MMBTU/yr
From the ice field	1137 MMBTU/yr
Total	5900 MMBTU/yr.

The comparison between cooling and heating requirements is now seen to be closer:-

Cooling 1137 + 63 (melt loss)	=	1200 MMBTU/yr.
Heating	=	846 MMBTU/yr

The contribution of the heat pump to the total cooling load is shown graphically, month by month, in Figure 2.

7. OUTLINE OF STORAGE SCHEMES

A full storage, as noted before, is one which can provide sufficient cooling from stored ice to serve the entire annual cooling load of the building. In theory, the chiller would be operated only for heating, its source of heat being the water in the soil mass which would be converted to ice by the end of the heating season.

Three concepts for storage have been examined. They consist of a bulk storage system which will be labelled the "Bathtub Concept", a trenched scheme which will be named the "Trench Concept" and a collection of drilled tubes which will be called the "Vertical Concept".

Description of the Bathtub Concept

This involves the mass excavation and replacement of soil in a pit which may have about 20% of the rentable area of the building to be served. The soil will be removed by large earth movers and deposited alongside the excavation. The front and back sides of the hole will have slopes suitable for equipment operation, while the longitudinal sides will be sloped as steeply as labour codes allow. The form of the excavation is shown in Figure 4 and the location of the storage in Figure 5.

Coils of 1/2 inch diamater polyethylene tubing will then be laid at the base of the excavation on centres which will be chosen analytically as shown in Appendix A. Soil will be returned to the excavation in successive layers with new coils of tubing placed above each layer. The soil will be graded and compacted at each level by heavy tracked vehicles. In the full storage example, the tubing will be laid at 2.232 ft. intervals, horizontally and vertically. Although less tubing of larger diameter could be used, the overall cost is least for the small diameter tube. Counterflow in the coils should assist dovetailing of the frozen cylinders as shown in Figure 6.

When the installation is complete there would be 10 layers of tubing with each of the 600 coils terminating, in valved connections, to 6 inch diameter pipes in a concrete header trench. The overall dimensions of the active portion of the excavation would be 314 feet long x 308 feet wide x 22.2 feet deep.

Above the active field there would be 2 feet of tamped fill to provide room for expansion of the water in the saturated soil when it freezes. Topping that, would be one foot of gravel sub base for the asphalt on the parking lot.

Figure 7 shows the smaller dimensions of a partial storage bathtub scheme which would be laid in 14 layers at 1.592 ft. centres.

The field would be saturated to the low water line shown in the header trench in Figure 8. Water would enter the field through 4 inch perforated drainage tile laid at 6.5 ft. centres. An emergency overflow would carry away surplus water if any should develop. The greater likelihood is that makeup water will be required to replace leakage from the field. A water makeup line will be provided for this purpose as shown in Figure 8.

The header trench will be equipped with insulation and an electric cable heater, as shown, to prevent water freezing within the trench.

The piping will be pressure tested before being placed in service. First, the headers will be tested with the 1300 circuit valves closed. Then the 650 circuits will be opened one at a time until all circuits are proven. Leaky circuits, if there are a few, will be permanently valved off. The tubing itself has indefinite life. It was run over on a concrete sidewalk many times by heavy equipment in a test with no sign of deteriorization.

A serious question about the potential for heaving and settling with the bathtub concept remains unanswered. It is interesting to note, however, that **no** settlement

has taken place over 5 years at the Illinois State University ice field barring an initial 9 inch drop when the bed was initially water filled. It should be noted, however, that no compacting was done on the backfill. On the positive side, it can be said that water is incompressible and should be held in place by the relatively impervious till at the boundary of the excavation. As well, the dry gravel overlay and asphalt surface should do an acceptable job of spreading heavy loads.

Originally it was considered that the ice field would require a waterproof liner. Reports by Trow Associates Ltd., however, revealed that the rate of percolation through the typical glacial till is so slow that an annual 10% water refill each fall was the most cost effective way to treat water losses.

Description of the Trenched Concept

Concern for the possibility of heaving or settlement with the bathtub concept led to the notion that this potential might be better controlled if the field contained areas of undisturbed soil. Hence, the arrangement of 30 inch wide trenches separated by 48 inch strips of solid soil.

Three tracked vehicles would be involved in the exercise of trenching. A backhoe with a 30 inch wide bucket would excavate to a depth of 22 feet. When a trench of 30 ft., or thereabouts length, was excavated, the backhoe would pick up coils of vertical piping previously set up as shown in Figure 9 and lower these into the trench. The crew making up coils alongside the trench would have no reason to approach the trench closer than the 10 feet allowed by the trench excavation act. They would anchor the coils in place on either side of the trench using tie lines run back from the top coil positioning bar to stakes set in the ground 10 ft. away from the trench. In the opinion of Petrex Ltd. personnel, who consulted on excavation, this method of tube installation would create no safety or code violation problems.

A loader would then move excavation material one bucket at a time to backfill the trench in layers of 3 feet or less. As each level of backfill was placed, a second backhoe with a tamper would consolidate the fill.

The trenches would be approximately 400 ft. in length. There would be 42 required for full storage and 13 for partial storage. See Figures 10 and 11. The tube spacings for full storage would be 30 inches and for partial storage 21 inches. The coils of tubing would be run in opposite directions to enable dovetailing of the frozen radius. See Figure 9.

Overburden for ice expansion and gravel topping would be the same as for the bathtub concept.

The header trench would be similar to the bathtub trench except that the headers would be on the backside of the trench to enable bends in the larger sub header piping. See Figure 12.

Description of Vertical Concept

A concept with the smallest potential for heaving or settlement involves an application of vertical boreholes similar to those used for ground source heating systems. An economical depth for a large system would be 250 ft. The holes would be 5 inches in diameter with 1 1/4" plastic U bends of piping. The piping would be grouted in place with concrete which would be pumped into the hole with a third tube which would be withdrawn during the fill process. The concrete is a precaution against piping collapse which might be caused by excessive expansion of frozen till.

The holes would be spaced at a maximum of 10 foot centres to avoid crossing during drilling. The arrangement for full and partial storage requires 803 and 300 holes, respectively, as shown on Figures 13 and 14. The header trench would be

as shown in Figure 15. One foot gravel fill would be used to cover the field and protect the sub header piping.

There is a problem of unknown impact when a U bend is used with a wide temperature range. At worst, heat would simply be exchanged between the two pipes and little heat would be drawn from the ice field. By feeding several holes in series, the temperature difference between the supply and return pipe in each hole would be reduced so that better results could be obtained drawing heat from the field. The number of holes which can be pumped in series is limited by the pipe resistance to flow. In the case of partial storage, a 16 foot fluid resistance limits series flow to three holes with a maximum temperature difference between supply and return pipes of $\frac{15F}{3}$ or 5F per hole. For full storage, six holes could be pumped in series for a temperature difference of $\frac{24F}{6}$ or 4F per hole.

Description of Heat Pump

Full Storage

The source of heating will be the large volume of saturated soil under the parking lot.

The heating agent will be a screw type glycol chiller located in the penthouse where shown on Figure 16. A single unit is deemed to be satisfactory for this building since the building is virtually self-heating with the lights alone.

There is an ample supply of water to freeze, as a source of heat, since the volume is related to the annual cooling requirement. This is five times the heating load in the case of full storage and approximately 1 1/2 times in the case of partial storage.

The screw type chiller has been chosen because of its ability to pump heat successfully from 25F glycol to 110F at a wide range of loads. The unit selected for this application is a Trane Model RTHA300. Its performance data is shown in Figure 3. This chiller can deliver the maximum heating requirement of 2.416×10^6 Btu/hr at the design condition noted above with 82% of its capacity. For partial storage, the heat pump is able to provide 262 tons of summer cooling with 38F glycol and 95F water off the condenser.

The average heating duty occurs at 27F as shown on Figure 17. The coefficient of performance of the heat pump at this condition is 4.4 as shown on Figure 18.

As a heating instrument the heat pump will be efficient, delivering heat for

$$\frac{1{,}000{,}000}{4.4 \times 3413} \times \$.10/\text{kWh} \text{ or } \$6.66/\text{MMBtu}$$

Although the average cost of electricity for GM is 5¢/kWh, the heat pump must be costed at 10¢/kWh because, in such a well insulated building, heating is a demand sensitive load. There is less than 100 hrs/kW use of demand for this equipment.

Natural gas, the chosen fuel for the GM building, will have a 7% higher cost -

$$\frac{1{,}000{,}000 \times \$5.00/\text{MCF}}{0.7 \text{ effcy.}} \text{ or } \$7.14/\text{MMBtu } (\$6.77/\text{GJ}).$$

A circuit diagram for the full storage scheme is shown in Figure 19. Connections to the cooling coil circuit will be made at points A-A on Figure 19 and Figure 20, taken from the GM office circuit diagram. Connections to the heating coil circuit will be made at B-B as shown on Figure 19 and Figure 21, the GM office heating circuit. Cooling coils will be fed with 700 GPM across a 24F range rather than 1460 GPM across the 11.5F range used in the GM design. Additional coil surface used for the ice field coolant range will be balanced by savings in smaller pipe and pipe

insulation, while savings in pump energy will be credited to the ice field energy quotient.

Heating will be by 110F water instead of 140F for terminal reheat coils and 180F for lobby heating and service areas. Compensation has been made in the costing to provide the additional heating surface necessary to permit the use of the inexpensive heat pump output. Some of the premium cost for additional coil surface is balanced by the reduction of heating circuits from two to one.

Some space will be retrieved by the elimination of the boilers and the relocation of DHW heaters and emergency generators as shown on Figure 22.

The glycol cooler is a major equipment item in the full storage scheme but only because the heating and cooling requirements are so imbalanced. It provides cooling redundancy, however, with its dual pumps and 30 - 1 hp fans. The cooler will operate continuously whenever the outdoor temperature is below 30F. It will be mounted on the roof of the building in place of the present water towers. See Figure 16. The sizing of the cooler is based on the 2100 hours/yr. of operation which are anticipated.

Heating water temperature will be mastered by an outdoor/indoor controller as shown on Figure 19. The heating sensor in the radiation circuit will control the capacity of the heat pump. If the temperature leaving the condenser drops below the controller setpoint, the heat pump will increase its capacity and lower the temperature of the leaving glycol from 32F to as low as 25F. This, in turn, will salvage more heat from the ice field by freezing soil further from the glycol tubing. In the full storage scheme, the heat pump would operate only for heating.

For cooling, a bypass would be opened around the heat pump and the glycol would be modulated in temperature by valve V_1, so that the supply to the cooling coil would always be at 38F in order to generate 45F air. Valve V_2 is provided in

the cooling coil circuit so that cooling can be done without icing up the cooling coils when the glycol output of the heat pump for heating is as low as 25F. There will be a few hours in the year when heating and cooling are required simultaneously.

Neither the pumps nor the heat pump will operate during unoccupied periods unless the office temperature reaches the boundary temperature of 5F above or below the setting of critical space thermostats.

Instrumentation will include thermometers across all heat exchangers and gauges across all pumps. A heat meter will also be provided to verify the balance of cooling left in the ice field. This might be used to cycle the glycol cooler in a harsh winter when an excess of ice was being frozen.

Partial Storage See Figure 23.

In this scheme the heating will be done by the heat pump, as before, but the heat pump will be used as a summer chiller, as well, doing the first 262 tons of cooling.

The glycol cooler will be smaller since the heating and cooling loads are now in better balance. A water tower must be added to reject condenser heat from the heat pump. Instead of providing the heat pump with a double condenser to separate tower water from clean circuit water, a less expensive heat exchanger has been provided for intermediate season cooling. Diversion of water from heating circuits to the heat exchanger is provided by V_3 which can modulate open as condensing temperature rises above its setpoint. The tower pump would operate at the same time with Valve V_4 preventing a sudden drop in condensing temperature. When the heating season is over, the heat exchanger and tower pump would be bypassed and the condenser would discharge heat directly to the tower.

Heating circuits, cooling circuits and instrumentation would remain the same as for full storage.

Since the ice field is the most costly component of the system, controls have been arranged to minimize the use of ice and preserve it during operation even at the expense of depreciating the COP of the heat pump.

8. ENERGY SUMMARY

The summary of energy cost for the GM diurnal design was made originally with a LOADSHAPER program. This was compared with the energy cost for a conventional system.

Although the ice storage system used 16% more energy, its demand saving features allowed it to operate for 1% less cost. If the comparison had been made in the City of Toronto with its demand sensitive rate, the ice storage system would have shown a greater saving.

The Meriwether program has been run with greater refinement to compare the diurnal ice storage with full and partial seasonal storage. Meriwether found the need for less total air circulation but the reduction in fan energy was credited to all three systems. Lower fan energy and a more accurate representation of lighting and 110 volt power allow the Meriwether printouts to show a lower cost than LOADSHAPER.

The Meriwether printout is included as Appendix B and the summary is included below.

A design and energy summary has also been done on a comparable ground source heat pump system by Water Furnace Ltd. The results are tabulated below and the backup is provided in Appendix C.

SUMMARY OF ENERGY COST

	Seasonal Storage				Diurnal Storage		Water Furnace	
	Full		Partial					
	$	¢/sf	$	¢/sf	$	¢/sf	$	¢/sf
Heating	6,378	2.4	6,378	2.4	8,571	3.2	5,439	2.0
Glycol Coolers	2,995	1.1	449	0.2	-		-	
Chillers,Pumps, Tower, etc.	6,150	2.3	23,883	8.8	34,262	12.7	22,867	8.5
Subtotal for Htg/Clg	15,523	5.8	30,710	11.4	42,833	15.9	28,306	10.5
Lights,Fans,110V power, DHW, Humidification	146,082	54.1	146,082	54.1	146,082	54.1	146,082	54.1
TOTALS $	161,605	59.9	176,792	65.5	188,915	70.0	174,389	64.6

All of the systems operate for heating and cooling at a remarkably low cost. The seasonal storage systems are less expensive than the diurnal storage, as expected. The Water Furnace system has been costed with its own proprietary system.

9. SUMMARY OF INITIAL COST

Costing of points of difference between the diurnal storage, which is now being installed in the GM building and the seasonal cooling systems has been carried out by Sayers & Assocs. Ltd. who are the contractors of record. Equipment and labour costs have been adjusted to the time of original tender.

Sayers pricing will terminate at the ice field. Costing for the ice field itself, including the concrete header trench, excavation and backfill has been provided by Petrex Ltd., a successful Toronto excavating contractor. This contractor has also included the laying of the tubing and headers since it was necessary to coordinate this closely with the excavation. Jointing for valves, tees and headers has involved the use of Calmac patent fittings which, with hand tightening, can resist a 250 psi test.

Pricing for vertical drilling and pipe laying for the vertical system has been provided by Water Furnace.

An estimate of the ice field costing is shown in Figure 24. These costs include a 10% contingency but do not cover the expense of removing extra fill since this could be used for aesthetic contouring of the property.

Combined costs are shown in the table below. Sayers did not provide a cost for trenching, wiring, controls structural bases or architectural changes. These costs have been estimated by others as shown.

SUMMARY OF INITIAL COST
SEASONAL ICE STORAGE

Item	Bathtub		Trenching		Vertical			
	Full	Part	Full	Part	Full	Part	Diurnal Ice Storage	Ground Source Storage
Ice Field from Figure 24	457,981	140,967	677,191	226,536	1,328,757	523,504	-	-
10% Contingency	45,800	14,100	67,700	22,700	132,800	52,400	-	-
Sub Total	14,500	155,065	744,891	249,236	1,461,557	575,904	-	1,780,000*
Methanol @ $2/USgal	14,500	5,700	14,900	5,900	13,700	5,100	-	-
Equipment, Piping, Labour from* Sayer's Ltd.	323,778	326,320	323,778	326,320	323,778	326,320	620,000	-
Trenching from building to ice* field @ $15/ft (from Petrex Ltd.)	3,000	3,000	3,000	3,000	3,000	3,000	-	-
Electrical @ $200/kW (from Ainsworth Electric	66,000	67,000	66,000	67,000	66,000	67,000	81,000	-
Additional cost for increase in Mechanical room floor area								
- chiller room	-	-	-	-	-	-	25,000	25,000
- boiler room	-	-	-	-	-	-	65,000	-
- ice storage room	-	-	-	-	-	-	175,000	-
Allowance for Automatic Control & Instrumentation	100,000	100,000	100,000	100,000	100,000	100,000	100,000	-
TOTAL	1,011,059	657,087	1,252,569	751,456	1,968,035	1,077,324	1,066,000	1,805,000

*See Appendix I for quotations

10. SENSITIVITY ANALYSIS

It is of interest to examine the impact on economics if changes were made to the design assumptions.

i) What if the heat pump were larger or smaller than 262 tons for the partial storage scheme.

ii) What if the heating load had been equal to the cooling load as originally intended.

iii) What if the electric rate had been more demand sensitive as it would have been if this example had been located in the City of Toronto.

iv) What if the water ratio for natural, disturbed and semi-disturbed ground had varied from those ratios suggested by Trow, 29%, 48% and 38% respectively.

v) What if the heat transfer coefficient for saturated ground had varied from those chosen, e.g., 1.6 Btu/F/hr/ft/ft. for frozen ground and 1.0 Btu/F/hr/ft/ft. for unfrozen ground.

10.1 Variance in the Size of the Heat Pump See Appendix E.

The size of the heat pump was related arbitrarily to the largest screw type chiller available from Trane. A larger unit would entail a different manufacturer or a $15,000 premium for a two unit installation.

Appendix D includes a Meriwether summary of hours of operation for cooling at percentile loads. From this data a graph was developed as shown on Figure 25. Some limitations on heat pump size are noted on the graph. If the heat pump is too large, the commensurate ice field will

become too small for heating. If the heat pump is below 215 tons capacity with 38F glycol it will be unable to manage the 140 tons of heat transfer required with 25F glycol and 110F condensing water necessary to serve the maximum heating load.

Proration of the costs of heat pump and ice field allowed the development of Figure 26 which compares the relative value of heat pump and ice field.

This graph indicates that the 262 ton selection was reasonable. It appears to be the size which provides the lowest initial cost of chiller and ice field for this example.

10.2 Variance in the Heating Requirement

At first glance it would appear that the ice field concept would benefit from a larger heating requirement. Then, the ice field would remain the same size and the glycol cooler would become smaller and less expensive.

However, there are problems with increasing the heating load. If the hourly requirement was more than 16% greater it would require a larger heat pump. If the annual heating requirement doubled, the glycol temperature necessary to extract heat from the ice field would drop and the energy necessary to operate the heat pump would begin to rise above the cost of gas.

It is to be hoped that installations such as the GM office will become typical since a heavy cooling load coupled with a light heating load seems to suit the ice field, especially for partial storage where the cost of the glycol cooler is less significant.

10.3 Variance in the Electric Demand Rate

A more demand sensitive rate such as that offered by Toronto Hydro would not change the relationship of system operating cost significantly as shown below:

Annual Cost of Heating & Cooling Energy

	Oshawa Rate 1988 - $/yr			Toronto Rate 1989 - $/yr		
Type System	Demand $3.68/kW	Energy @ $0.037/kWh	Total	Demand @ 11.96/kW	Energy @$0.029/kWh	Total
Full Seasonal Ice Storage	6,064	9,459	15,523	19,708	7,434	27,147
Partial Seasonal Ice Storage	10,711	19,999	30,710	34,811	15,717	50,528
Diurnal Ice Storage	11,934	22,259	34,183	38,786	17,494	56,280

The requirement for electric demand and energy are closer than expected, so the demand sensitivity of the electric rate will have commensurately less impact on the result.

10.4 Variance in Ground Water Ratio See Appendix F

The initial cost of the ice field was examined for several water ratios with the following results:

Bathtub Concept

	Full Storage $	Partial Storage $
Base Cost with 0.48 ratio	457,980	140,965
For 0.50 ratio	deduct 13,655	deduct 3,160
For 0.30 ratio	add 213,800	add 51,465

Trenched Concept

	Full Storage $	Partial Storage $
Base Cost with 0.38 ratio	677,191	226,536
For 0.425 ratio	deduct 26,300	deduct 7,785
For 0.25 ratio	add 128,230	add 43,000

Vertical Concept

	Full Storage $	Partial Storage $
Base Cost with 0.29 ratio	1,321,359	516,740
For 0.35 ratio	deduct 34,163	deduct 16,500
For 0.20 ratio	add 96,150	add 34,900

The natural fill has an average water ratio of 0.29. After being disturbed and compacted this changes to 0.48 according to the Trow analysis shown in earlier reports. This justifies a 0.38 ratio for the trenched scheme which is half disturbed and a 0.29 ratio for the undisturbed soil around the drill holes.

10.5 Variance in the Heat Transfer Coefficient See Appendix G.

The initial cost of the ice field was examined for several heat transfer coefficients in wet ground with the following results:

Bathtub Concept

	Full Storage $	Partial Storage $
Base Cost with 1.0 factor	437,980	140,965
For 1.5 factor	deduct 4,300	deduct 2,632
For 0.7 factor	add 15,650	add 5,376

Trenched Concept

	Full Storage $	Partial Storage $
Base Cost with 1.0 factor	677,191	226,536
For 1.5 factor	deduct 118,118	deduct 36,470
For 0.7 factor	add 159,224	add 45,850

Vertical Concept

	Full Storage $	Partial Storage $
Base Cost with 1.0 factor	1,321,359	516,740
For 1.5 factor	deduct 367,900	deduct 135,000
For 0.7 factor	add 442,361	add 167,000

The heat transfer coefficient appears to be a significant factor for the trenched and vertical schemes, well worth the price of an initial laboratory analysis.

11. CONCLUSIONS

Simple Payback Comparison of Systems

If the cost of the diurnal ice system was subtracted from the cost of seasonal storage and the result divided by the savings in energy, the simple payback would be as follows:

Bathtub	Full Storage	0 yrs
	Partial Storage	0 yrs
Trenched	Full Storage	6.8 yrs
	Partial Storage	0 yrs
Vertical	Full Storage	33 yrs
	Partial Storage	1.0 yrs.

Present Worth Comparison of Systems

With money worth 10% and escalation at 5%, the present worth factor for 20 years is 12.5. See Figure 27

Present worth of energy will then be as follows:

	$/yr	P.V. $/yr x 12.5	Difference
Diurnal Ice	188,915	2,361,438	-
Full Seasonal	161,605	2,020,062	341,376
Partial Seasonal	176,792	2,209,900	151,538

The adjusted first cost of the systems will then be:-

	Initial Cost $	Deduct Difference in P.V. of Energy $	Net $	Ranking
Diurnal Ice	1,066,000		1,066,000	6
Bathtub Full	1,011,059	341,376	669,683	3
Partial	657,087	151,538	505,549	1
Trenched Full	1,252,569	341,376	911,193	4
Partial	751,456	151,538	599,918	2
Vertical Full	1,968,035	341,376	1,626,659	7
Partial	1,077,324	151,538	925,786	5

On this basis the partial seasonal storage outperforms the full seasonal storage and diurnal storage.

The bathtub concept is the least expensive seasonal system followed by the trenched and vertical.

Susceptibility of Systems to Maintenance

The bathtub and trenched systems require water makeup each fall to replace peripheral leakage into the surrounding glacial till. The vertical system assumes a naturally saturated ground for at least 225 feet (69 m) of its depth and, therefore, needs no water replenishment. Water makeup to the bathtub and trenched systems is estimated to cost about $1,000/yr.

Susceptibility to heaving and settlement of the parking surface remains unproven for all systems although the vertical system appears to have the least liability. Opinions on rise and fall of the parking surface have been expressed both pro and con. It is likely that the disturbed soil bed will fall when it is fully saturated. At this time the gravel top layer should be graded and rolled before laying asphalt.

Heaving or settlement after this procedure will have to be proven by actual experiment.

Area Required

The area required for the ice field varied from 30,000 sq.ft. (3000 m^2) to 90,000 sq.ft. (9000 m^2) or from 11% to 33% of the gross building floor area.

Since the parking lot for many buildings exceeds the area of the floor space, it appears that there would always be area for an ice field whenever there is outside parking.

Equipment Breakdown

Heating failure is not a large problem in the GM office since the lights will heat the building if the outside air ratios are reduced.

Cooling failure is more likely to beset the GM building with the diurnal storage than with the ice field. Although there are two chillers, the system will be compromised with the outage of one. Although the seasonal storage schemes involve only one chiller, the ice field itself provides an immense cooling standby. It is possible that glycol leaks could develop in the ice field, however. This would be evidenced by a dropping level in the expansion tank. The bathtub concept would lose only one of 590 circuits on full storage and one of 468 circuits in the partial storage. The trenched concept would lose one in 188 panels with full storage and one in 68 panels in partial storage. All trenched circuits would be pretested before the subheaders were covered.

Duplicate pumping has been provided for all systems in critical services.

Finally

Seasonal storage has been the pursuit of designers for many years. Until now the concepts which have been presented have been uneconomic.

It now appears that there is a chance for seasonal storage to prevail over other types of systems in both original and operating cost.

Sayers Ltd. completed estimates on the original design to prove that the diurnal ice storage, with low temperature air supply, was cheaper than a conventional system. The LOADSHAPER program then showed that energy was less costly, as well.

Now there is a seasonal system which can improve still further on initial and operating cost.

This is a pleasant surprise. The partial storage system is worthy of prototyping experiments to validate its advantages.

12. RECOMMENDATIONS

The Heaving and Settlement of the Paving Surface

A small excavation should be made in an area with typical glacial till. The dirt should be replaced in the hole and tamped down with the same tracked vehicles which would have been used for the bathtub concept of seasonal storage.

The fill should then be examined for initial subsidence. This will establish the extent of the initial drop in level when the ice field is flooded.

Funds required for this experiment, together with supervision and report, would be $10,000.

Next, funds should be provided to Prof. Ed Francis of Illinois State University to freeze and thaw his original installation measuring approximately 15 ft x 8 ft x 12 ft deep. Dr. Francis claims there has never been any heave or settlement of his ice field in two operating seasons. However, no official measurement was ever taken to prove this.

Funds for this step are thought not to exceed $10,000 because the ice field, heat exchanger and glycol cooler are all still in place.

Next Step

If the experiment at the University of Illinois proves minimal heating and settlement of the surface of the ice field, the concept is ready for trial on a small new building. These are proceeding at a good rate in the Toronto environs, so it should not be difficult to find a candidate if the government provides supporting funds for standby equipment. It may also be possible to add the system to an existing building where the energy cost is known to be excessive. A number of schools are available for this purpose. Many are now operating in the summer and would also benefit from the cooling.

Prepare for a cost of $100,000.

Verification of Water Ratio, Heat Transfer Coefficient and Water Leakage Factor

This should proceed with the first excavation and soil replacement.

Consulting assistance can be obtained from Geo-technical firms to analyze the degree of compaction, the water ratio of the soil before and after flooding and the flooded heat transfer coefficient.

While this is underway, the excavation will be covered with a vinyl film and water will be added over a period of several months to top up the level under the cover. The water makeup will be measured.

For this work, an allowance of $10,000 should be made.

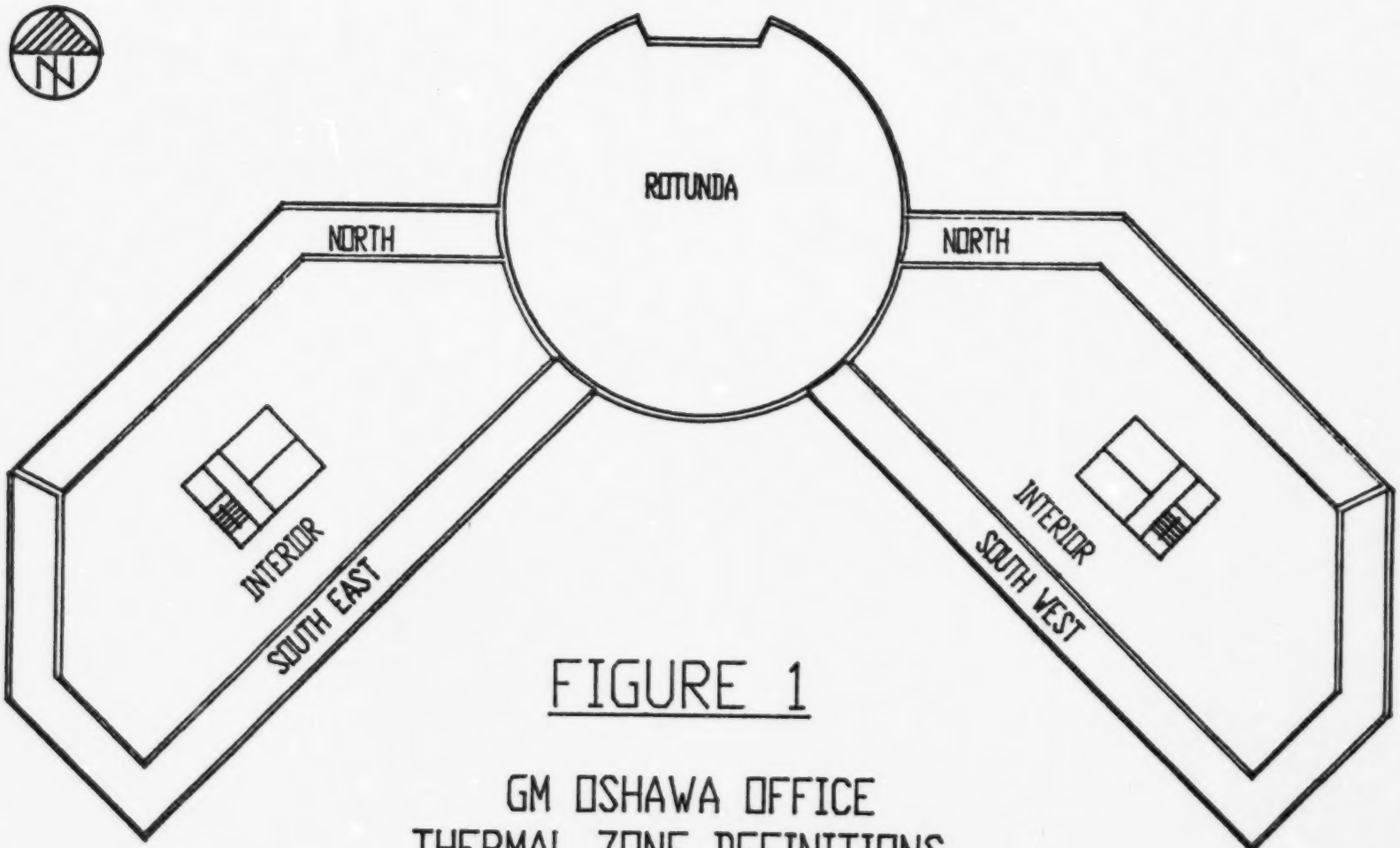


FIGURE 1

GM OSHAWA OFFICE
THERMAL ZONE DEFINITIONS

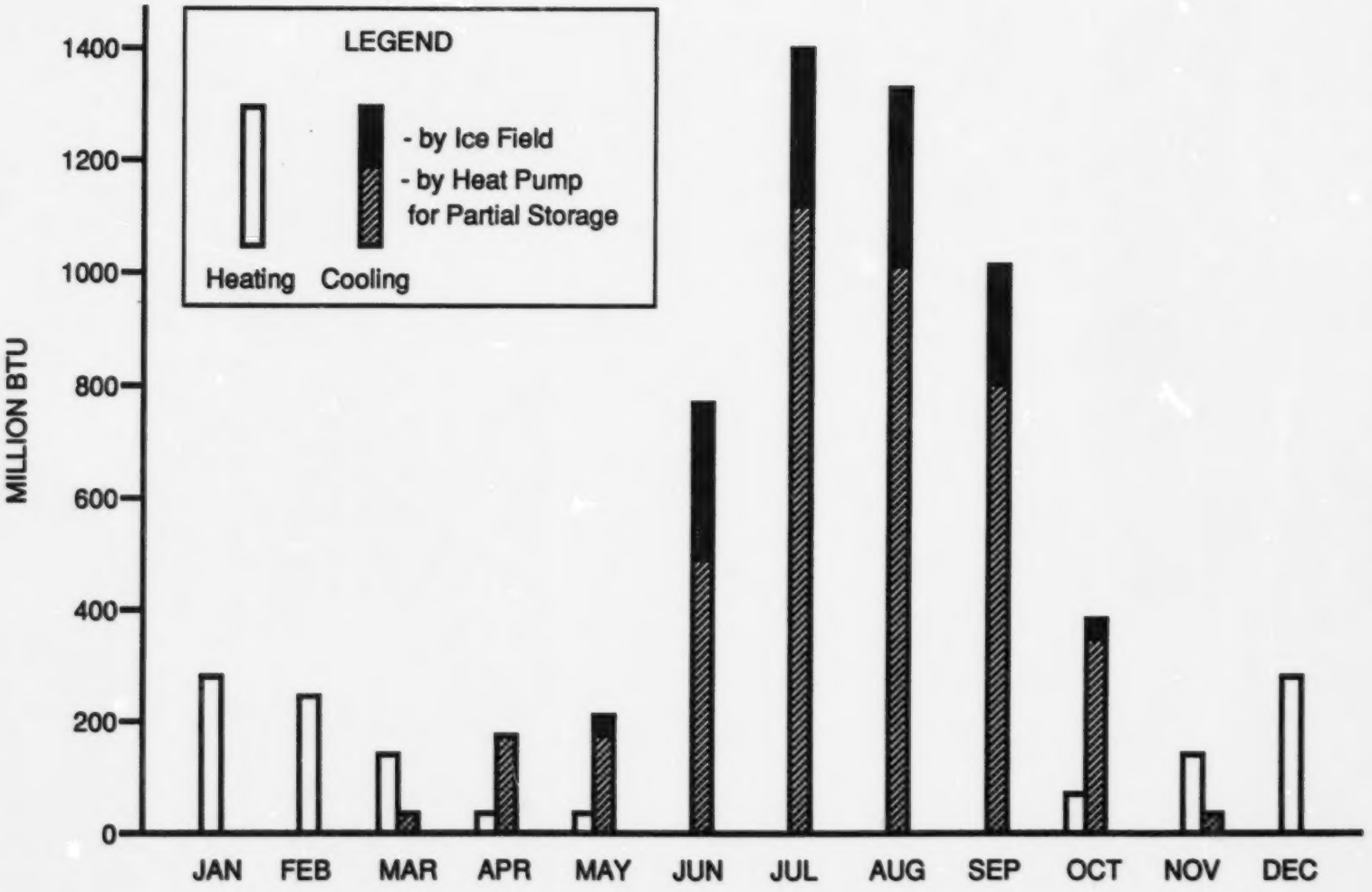


Fig. 2 **Monthly Distribution of Heating and Cooling Loads**

LEAVING CONDENSING WATER TEMPERATURE

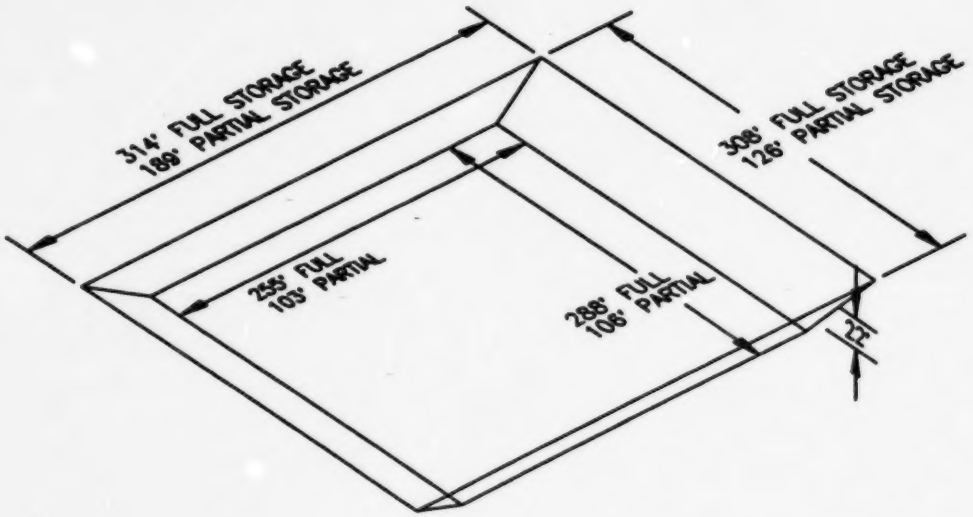
Leaving Glycol Temp	70F			80F			90F			95F			100F			110F		
	Tons	kW	kW/ton	Tons	kW	kW/ton	Tons	kw	kW/ton	Tons	kW	kW/ton	Tons	kW	kW/ton	Tons	kW	kW/ton
15	162	146	0.90	153	171	1.12	144	198	1.38	140	212	1.51	136	227	1.67	127	259	2.04
20	189	146	0.77	180	170	0.94	170	198	1.16	165	213	1.29	159	228	1.43	148	260	1.76
25	218	146	0.69	208	170	0.82	196	198	1.01	193	213	1.10	189	228	1.21	171	261	1.53[2]
30	248	145	0.58	237	170	0.72	224	197	0.88	217	213	0.98	210	228	1.09	195	262	1.34
35	278	145	0.52	266	169	0.64	253	197	0.78	246	212	0.86[1]	238	228	0.96	221	263	1.19
38	296	145	0.49	284	169	0.60	270	196	0.73	263	211	0.80	255	227	0.89	237	262	1.11
40	308	145	0.47	296	169	0.57	282	196	0.70	274	211	0.77	266	227	0.85	248	262	1.06
45	337	145	0.43	326	168	0.52	312	196	0.63	304	211	0.69	296	227	0.77	277	262	0.95
50	367	145	0.40	356	168	0.47	342	195	0.57	334	210	0.63	326	226	0.69	307	261	0.85

[1] Highest Summer Energy

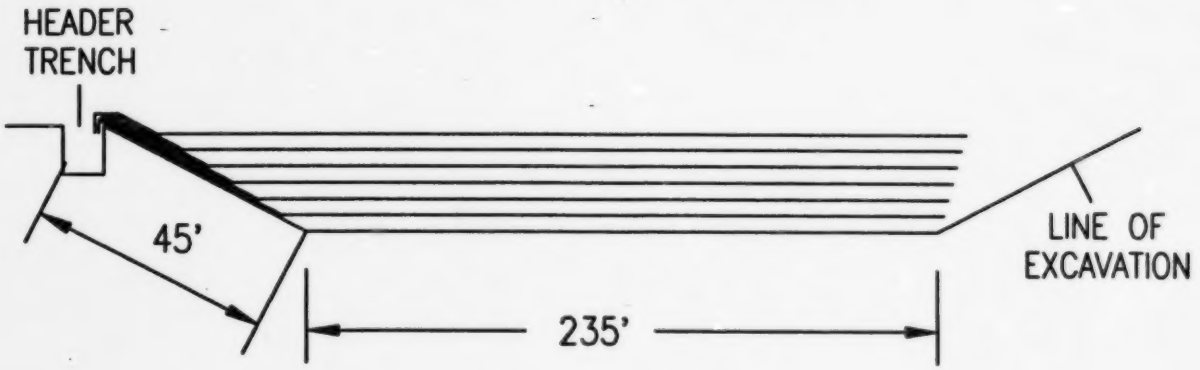
[2] Highest Winter Energy

FIGURE 3

TABLE FOR SCREW CHILLER PERFORMANCE

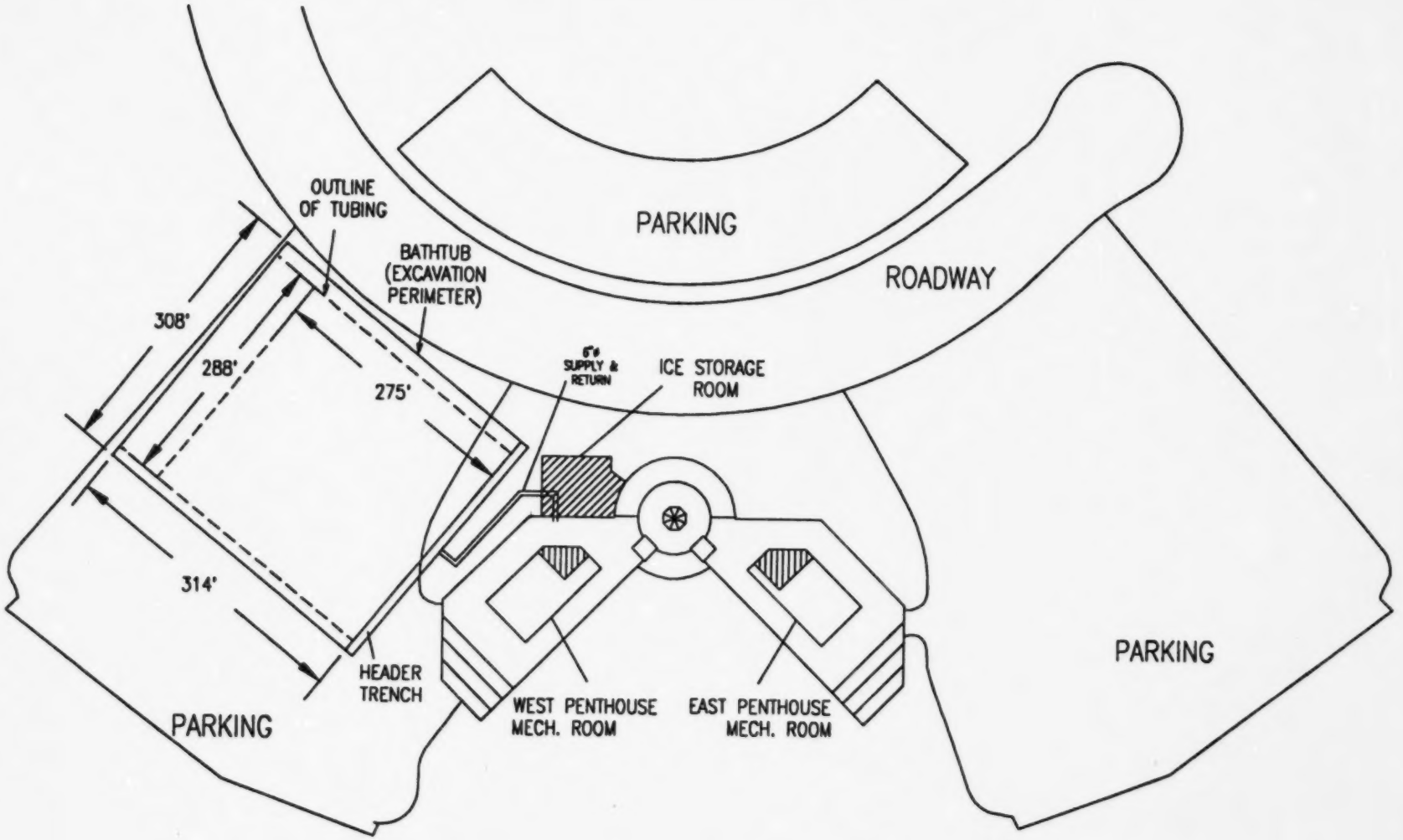


CONFIGURATION OF BATHTUB ICE FIELD



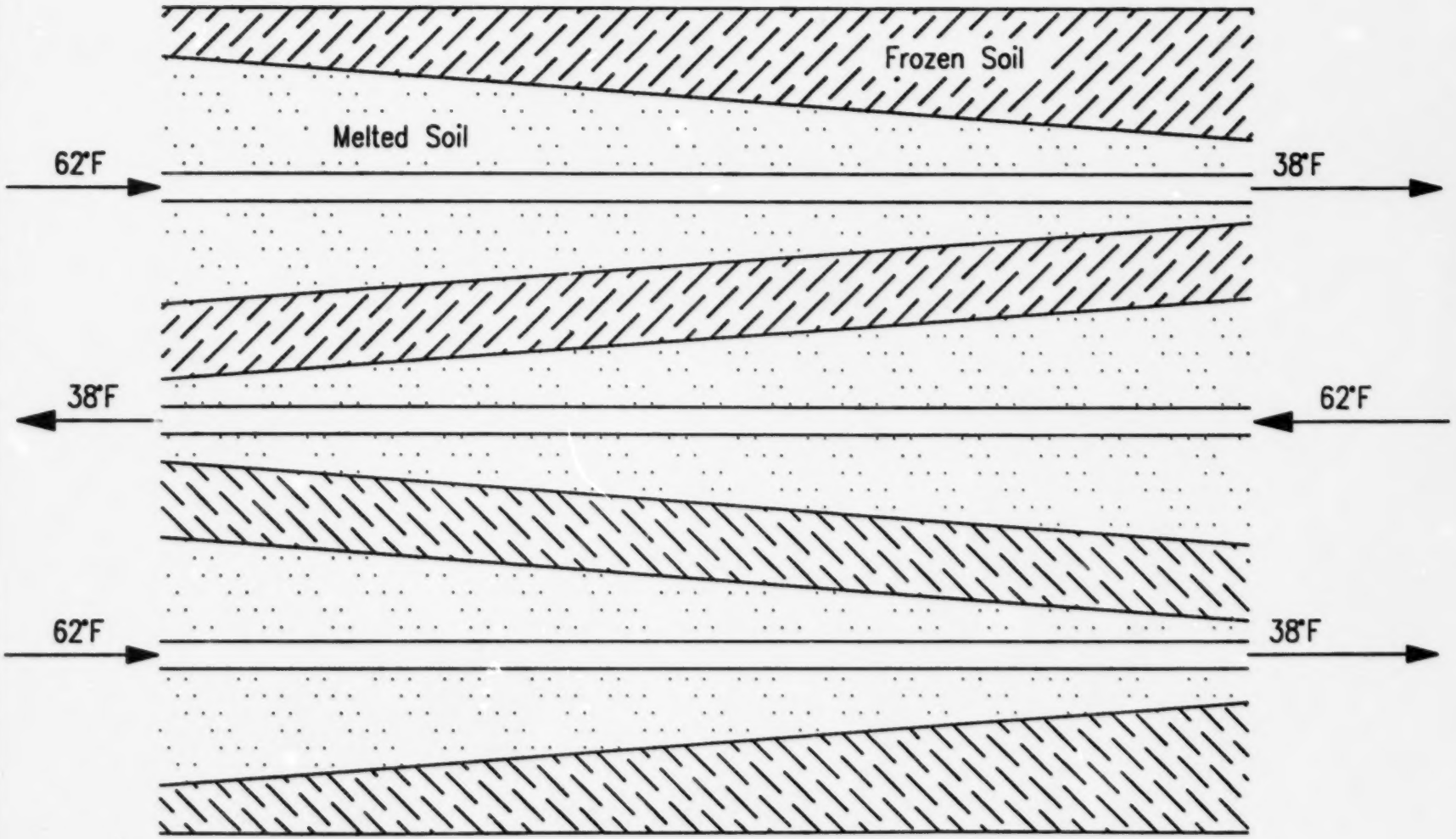
BATHTUB SECTION SHOWING TUBING CONFIGURATION

FIGURE 4



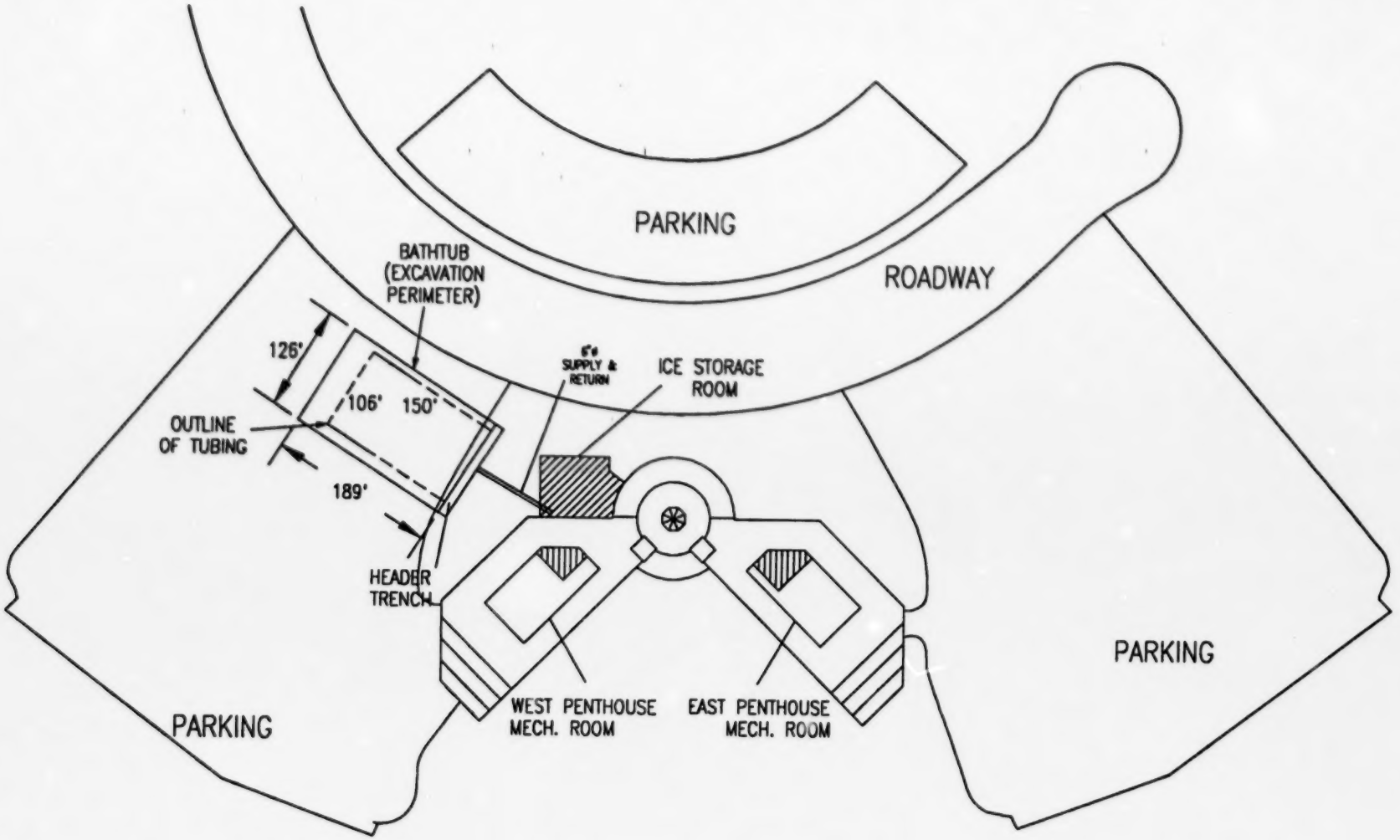
PLOT PLAN OF FULL
STORAGE BATHTUB

FIGURE 5



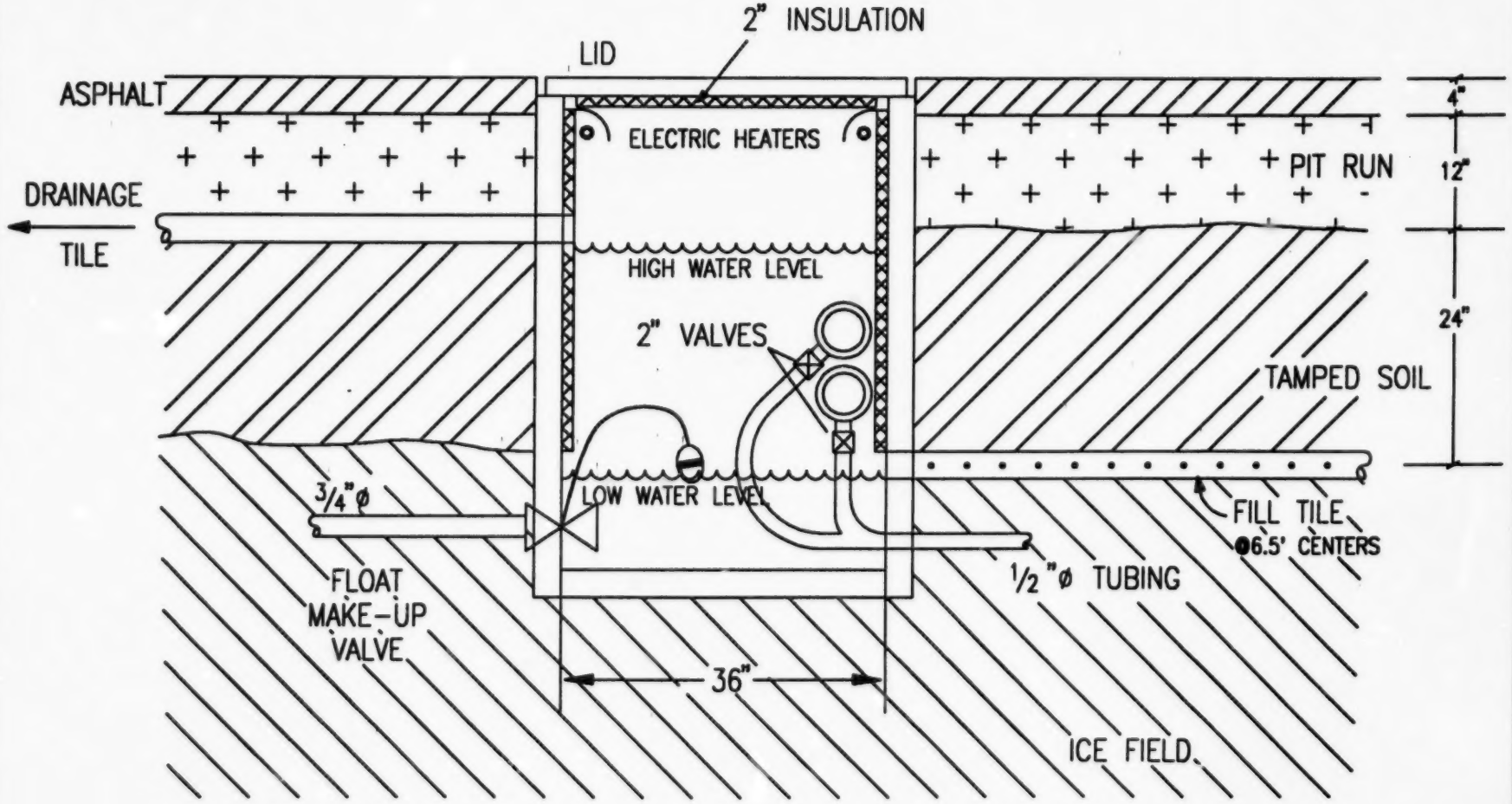
COUNTERFLOW TUBING CONCEPT

FIGURE 6



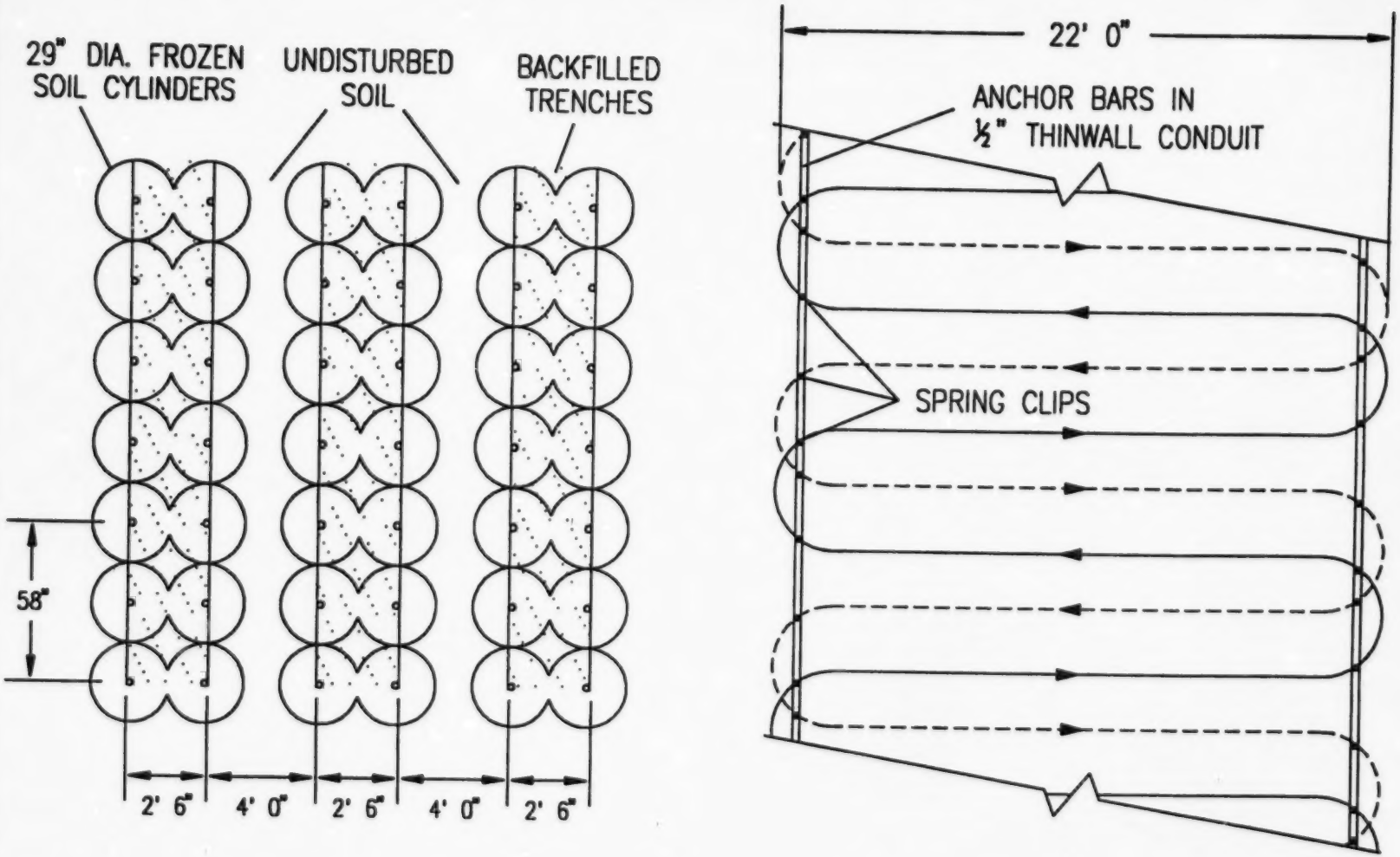
PLOT PLAN OF PARTIAL
STORAGE BATHTUB SYSTEM

FIGURE 7



DETAIL OF A CONCRETE HEADER TRENCH
FOR BATHTUB CONCEPT

FIGURE 8

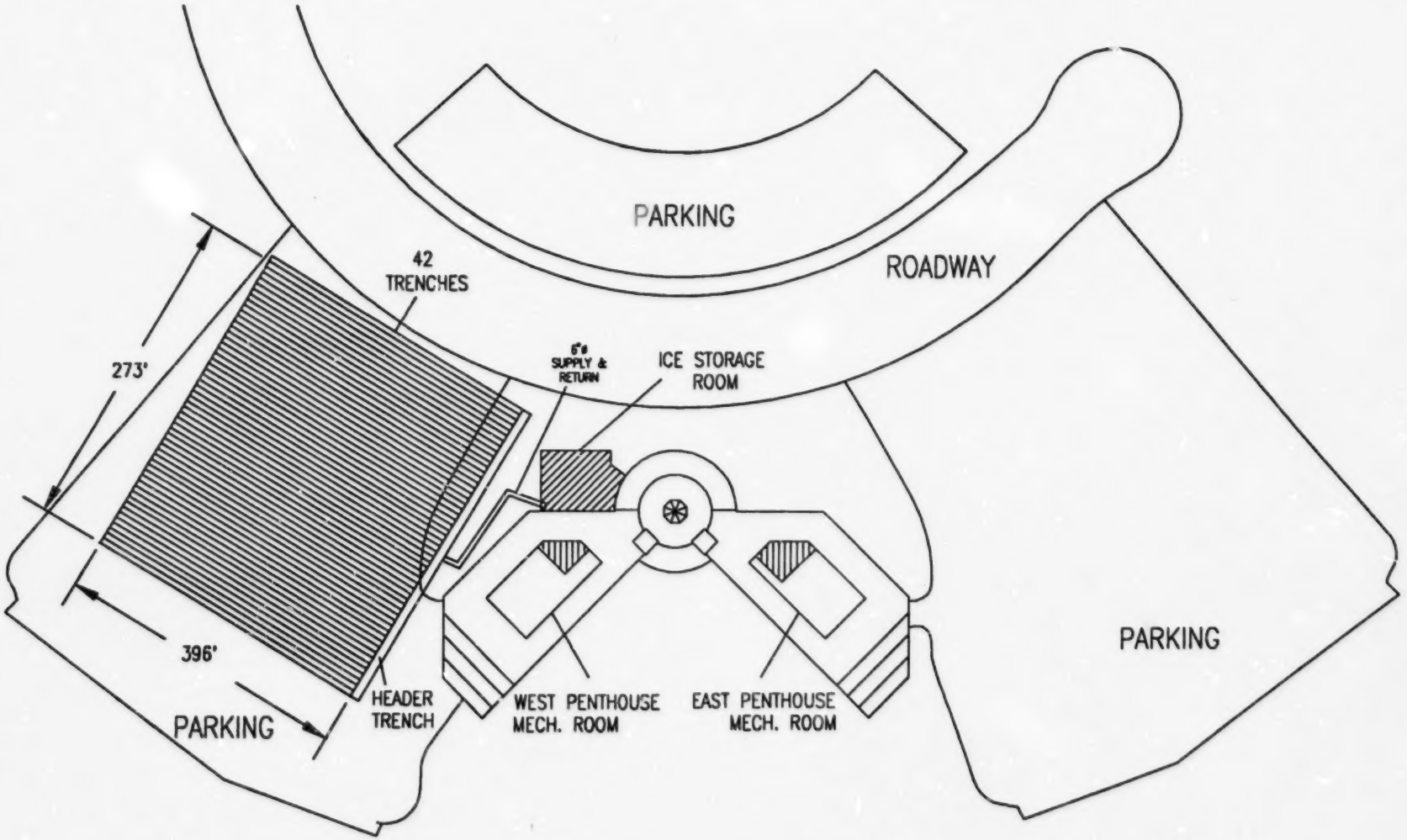


CUT AWAY PLAN

VERTICAL ELEVATION

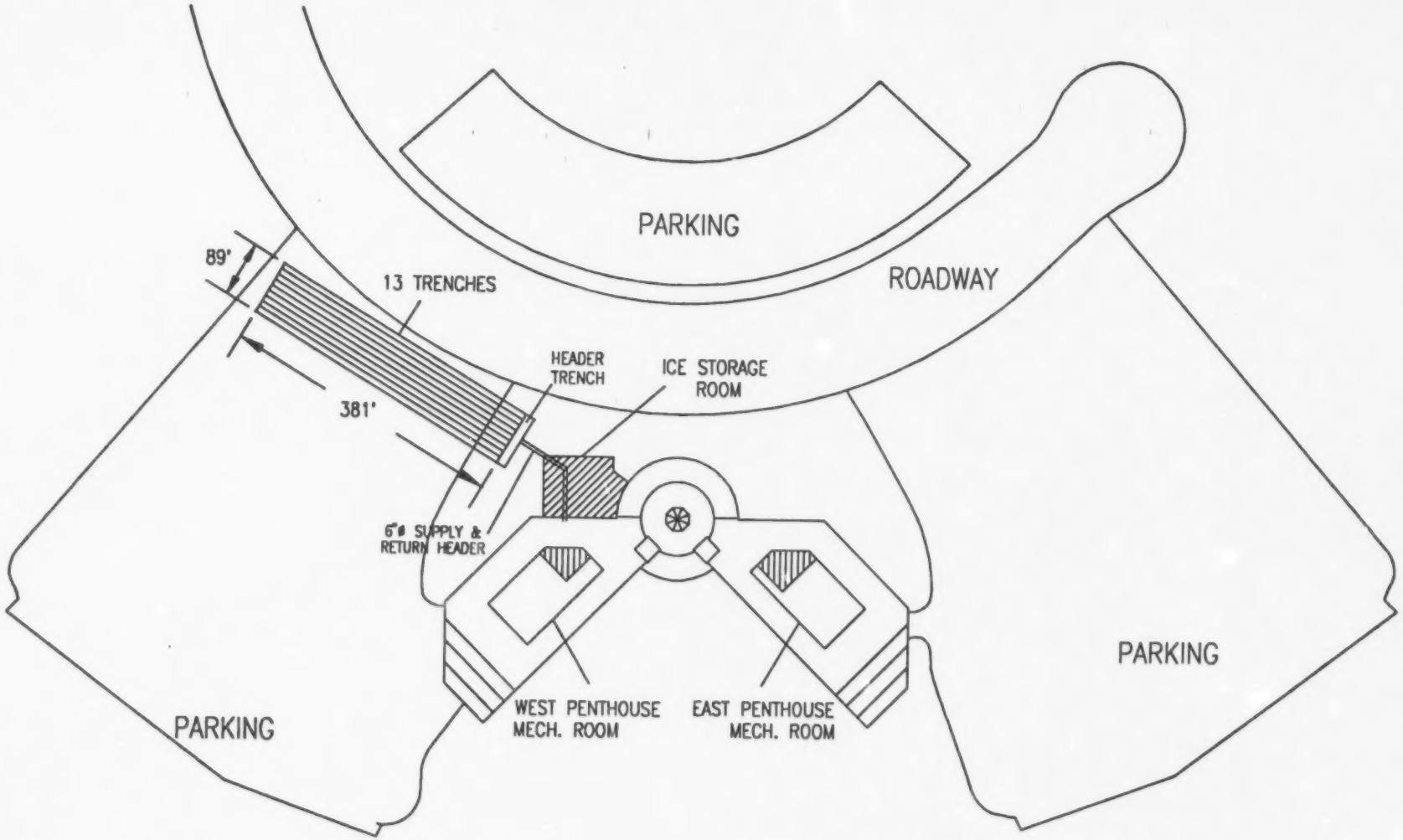
ARRANGEMENT OF TUBING FOR TRENCHED SOIL FILL – FULL STORAGE

FIGURE 9



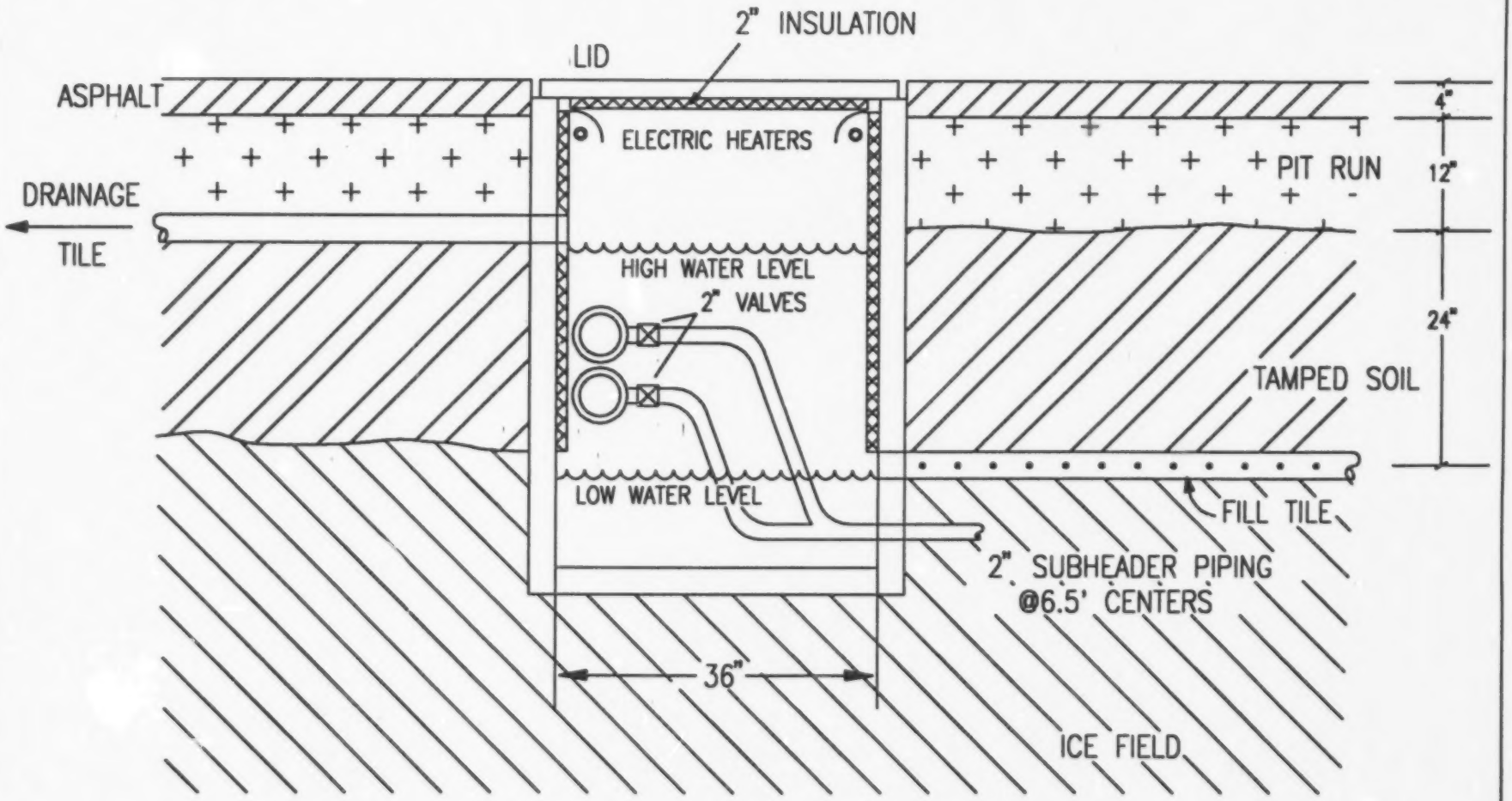
PLOT PLAN OF FULL
STORAGE TRENCH SYSTEM

FIGURE 10



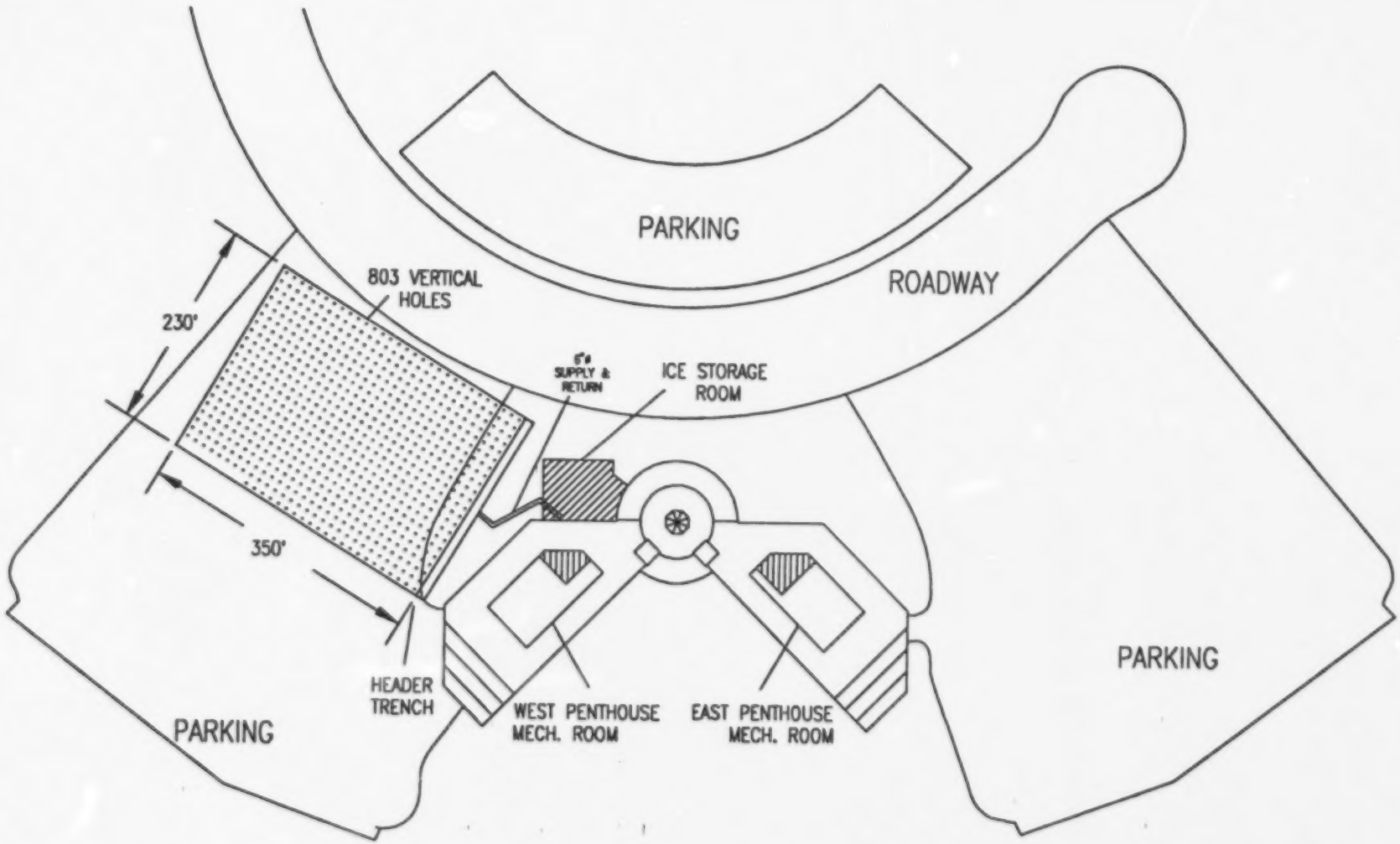
PLOT PLAN OF PARTIAL
STORAGE TRENCH SYSTEM

FIGURE 11



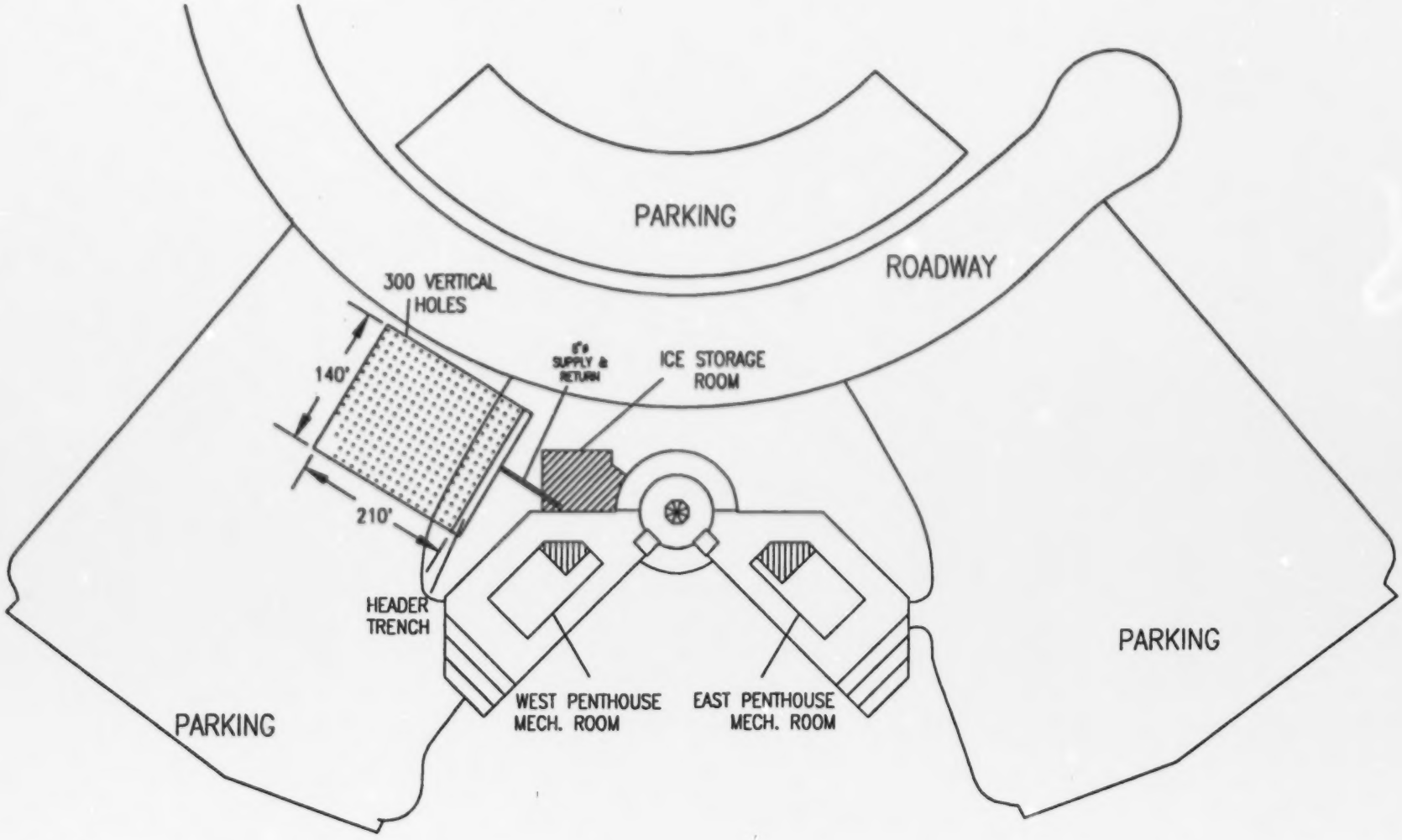
DETAIL OF CONCRETE HEADER TRENCH
FOR TRENCH CONCEPT

FIGURE 12



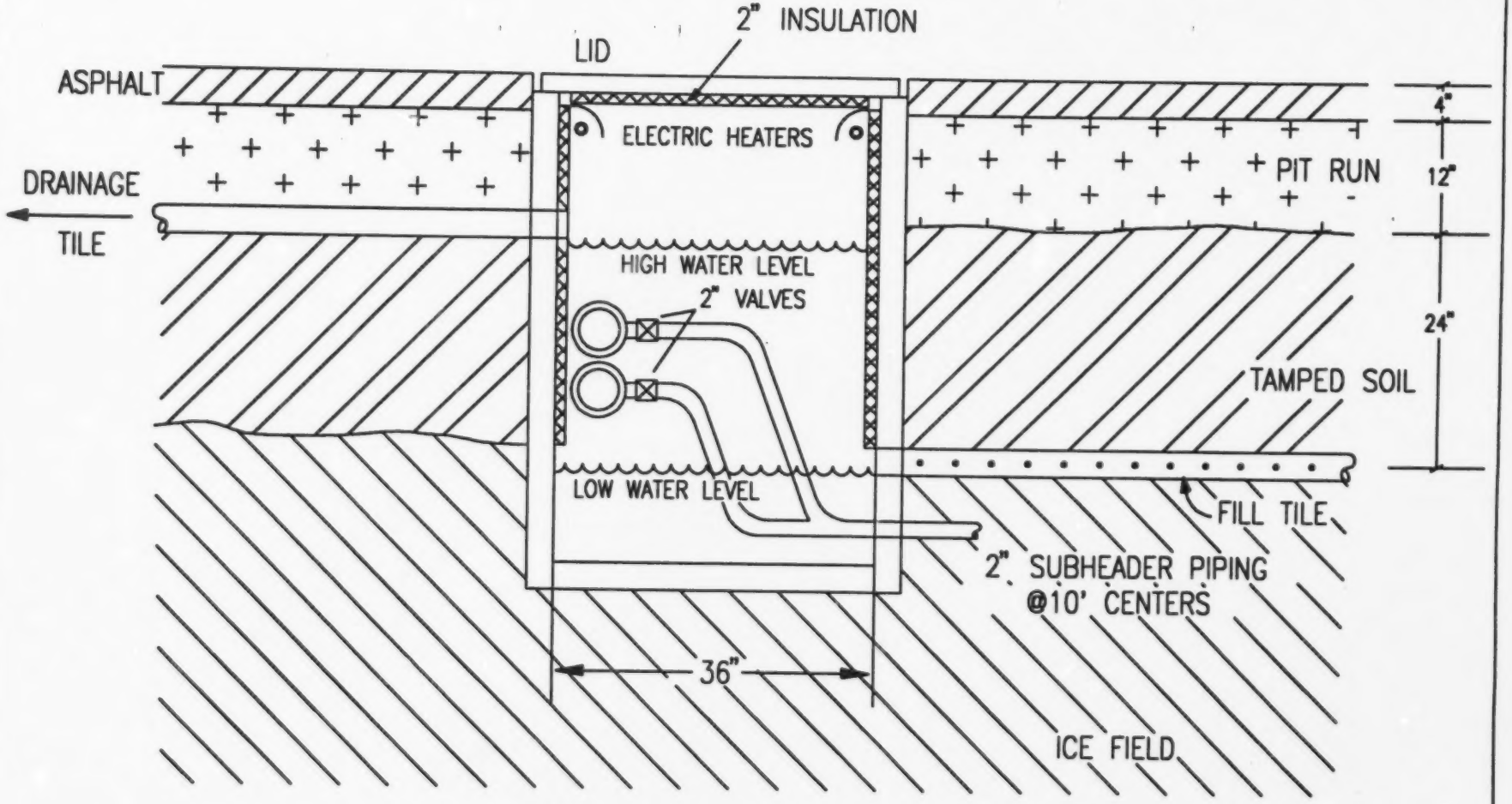
PLOT PLAN OF FULL
STORAGE VERTICAL HOLE SYSTEM

FIGURE 13



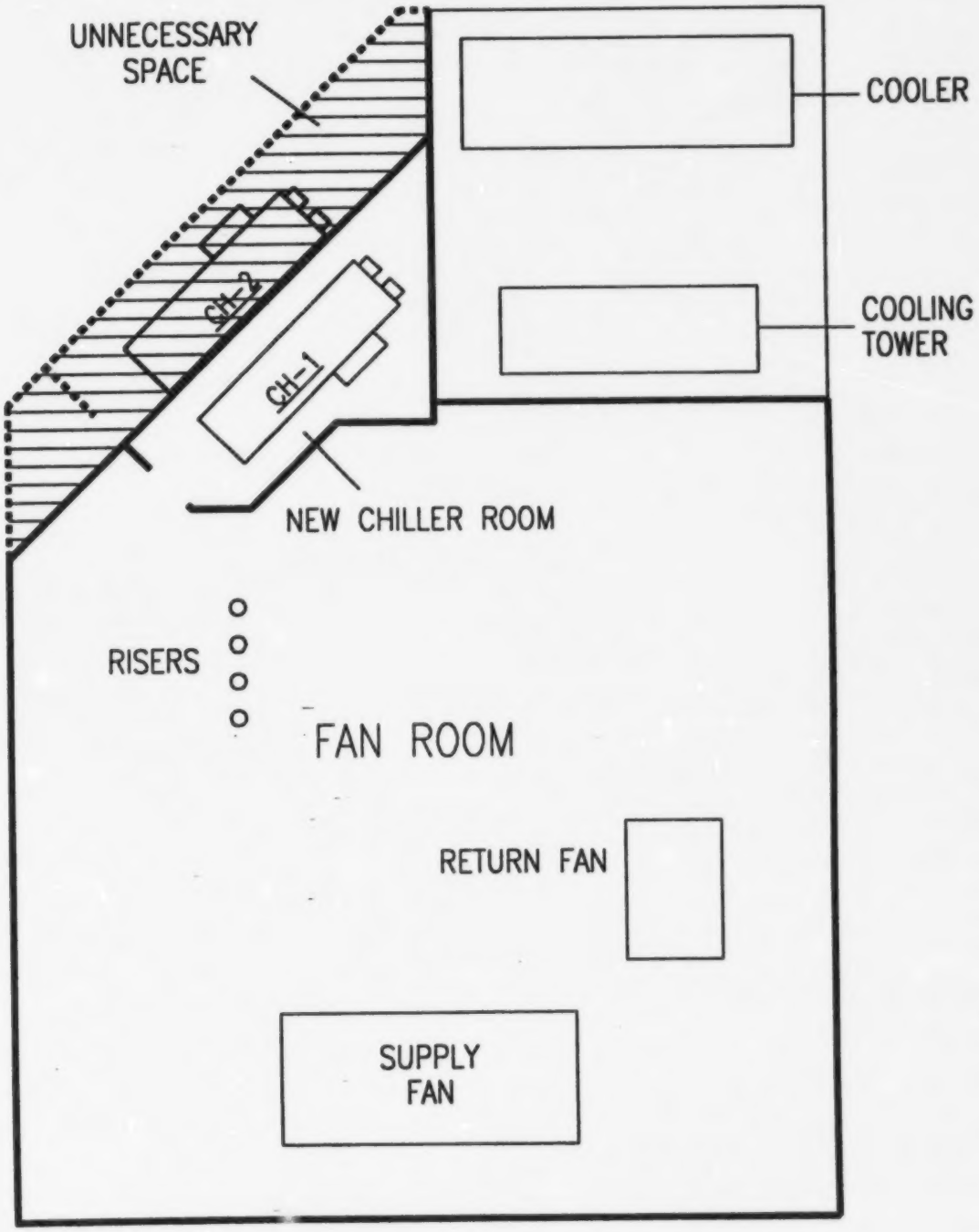
PLOT PLAN FOR PARTIAL
STORAGE USING VERTICAL HOLE SYSTEM

FIGURE 14



DETAIL OF CONCRETE HEADER TRENCH
FOR VERTICAL CONCEPT

FIGURE 15



WEST PENTHOUSE:
EQUIPMENT LOCATION FOR
PARTIAL STORAGE

SCALE
1"=12'

FIGURE 16

FIGURE 17

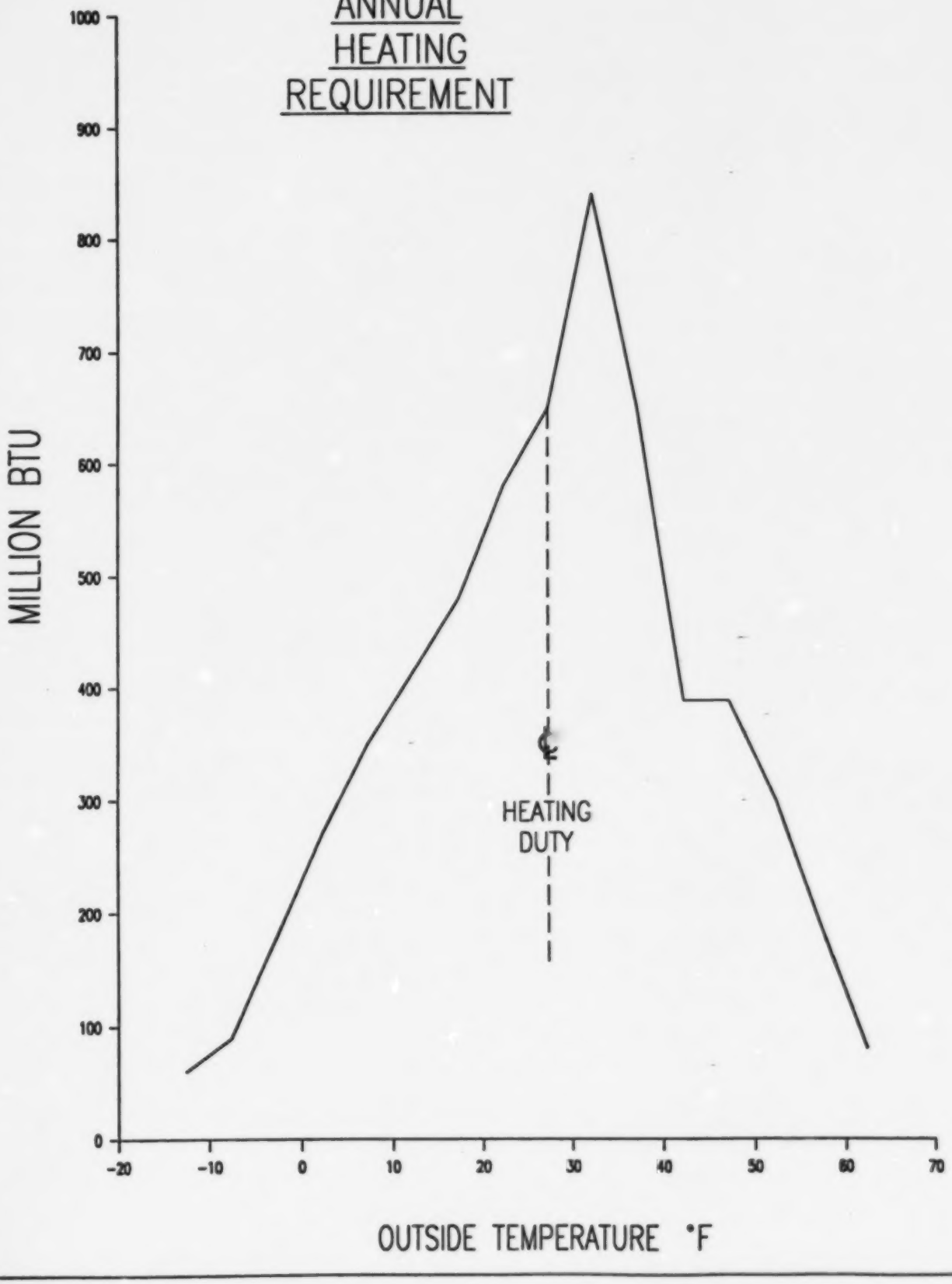
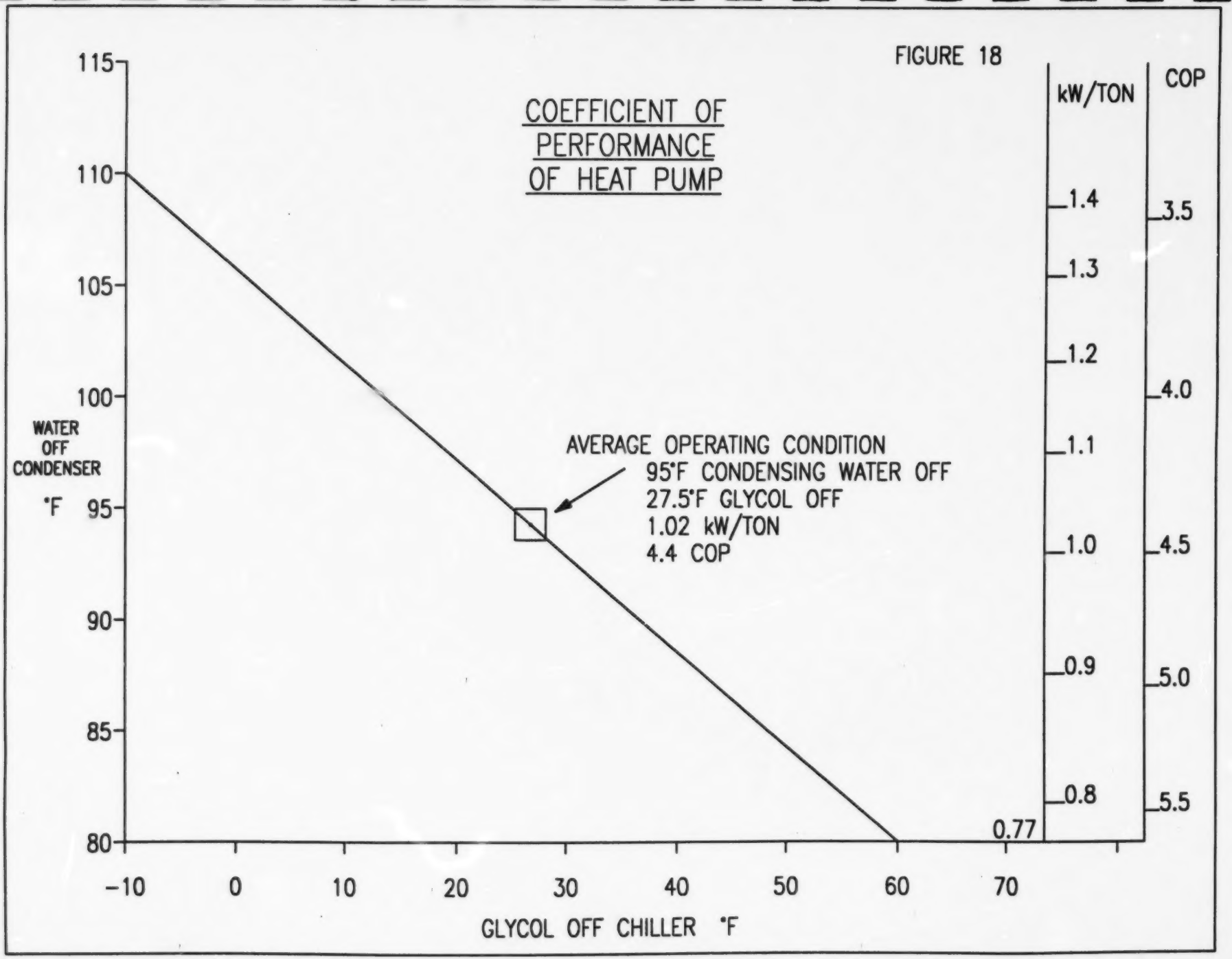

ANNUAL
HEATING
REQUIREMENT
MILLION BTU
1000
900
800
700
600
500
400
300
200
100
0
HEATING
DUTY
-20
-10
0
10
20
30
40
50
60
70
OUTSIDE TEMPERATURE °F

FIGURE 18


COEFFICIENT OF PERFORMANCE OF HEAT PUMP
kW/TON
COP
115
110
105
100
95
90
85
80
WATER OFF CONDENSER °F
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.77
3.5
4.0
4.5
5.0
5.5
AVERAGE OPERATING CONDITION
95°F CONDENSING WATER OFF
27.5°F GLYCOL OFF
1.02 kW/TON
4.4 COP
-10
0
10
20
30
40
50
60
70
GLYCOL OFF CHILLER °F

FULL STORAGE CIRCUIT

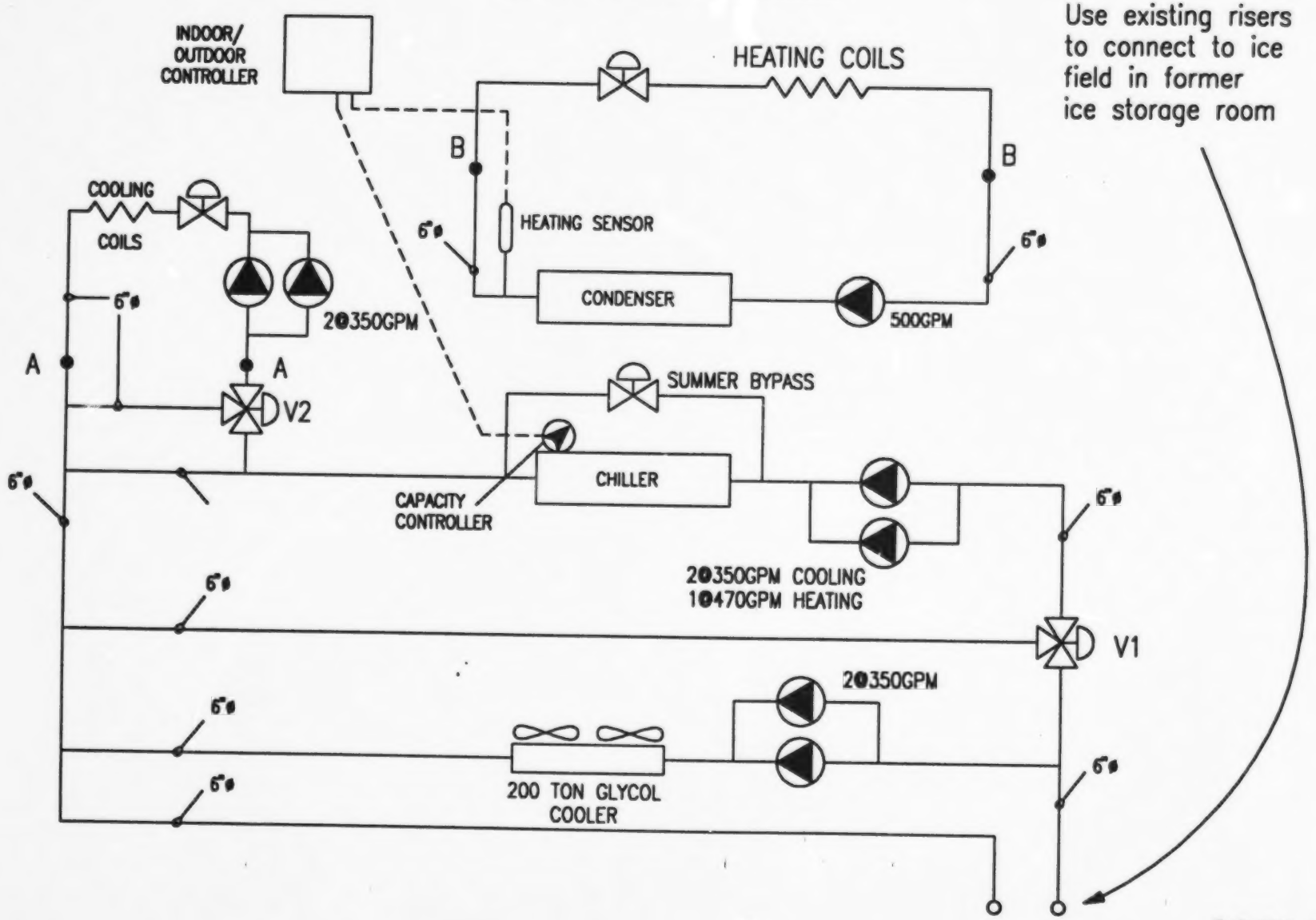
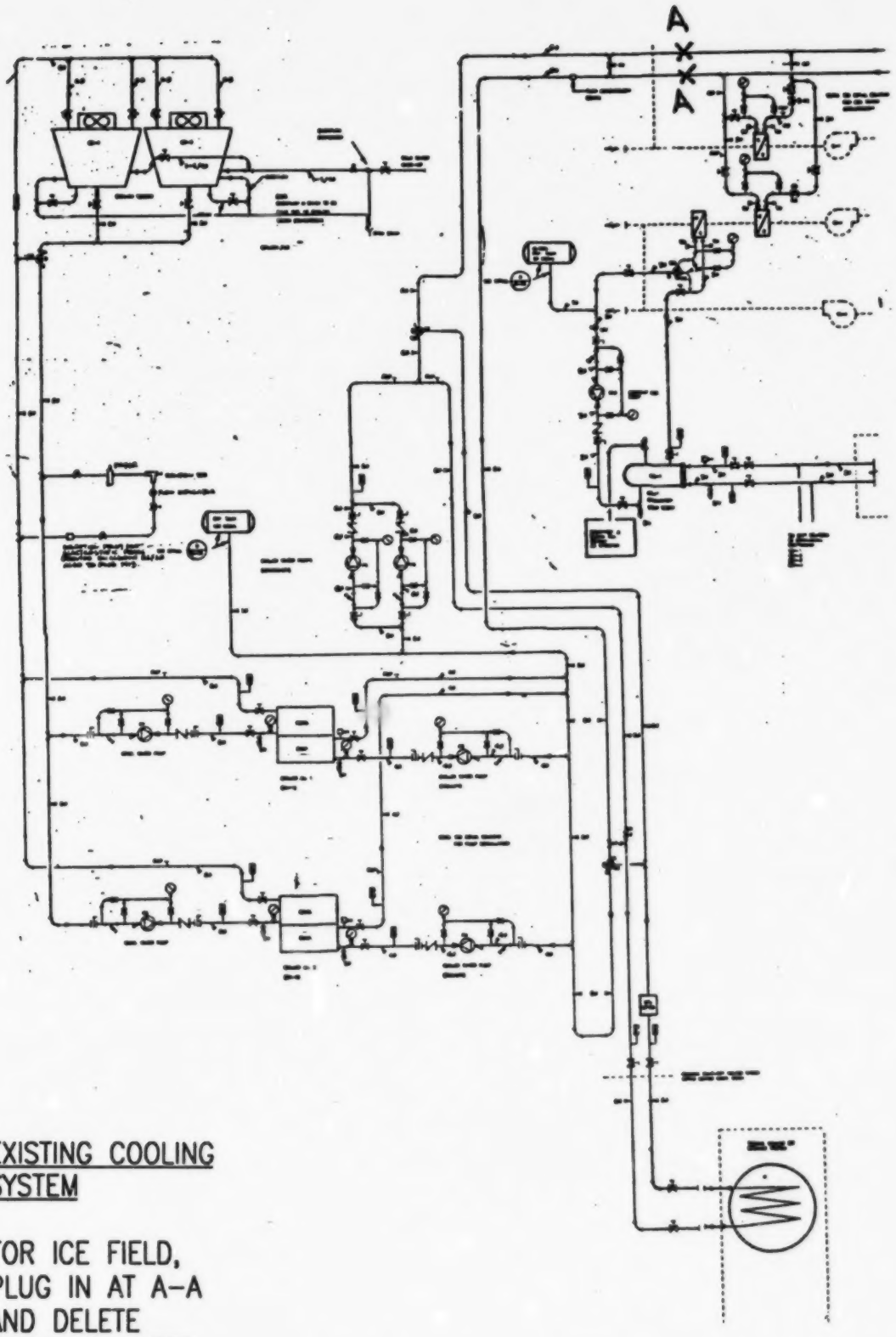


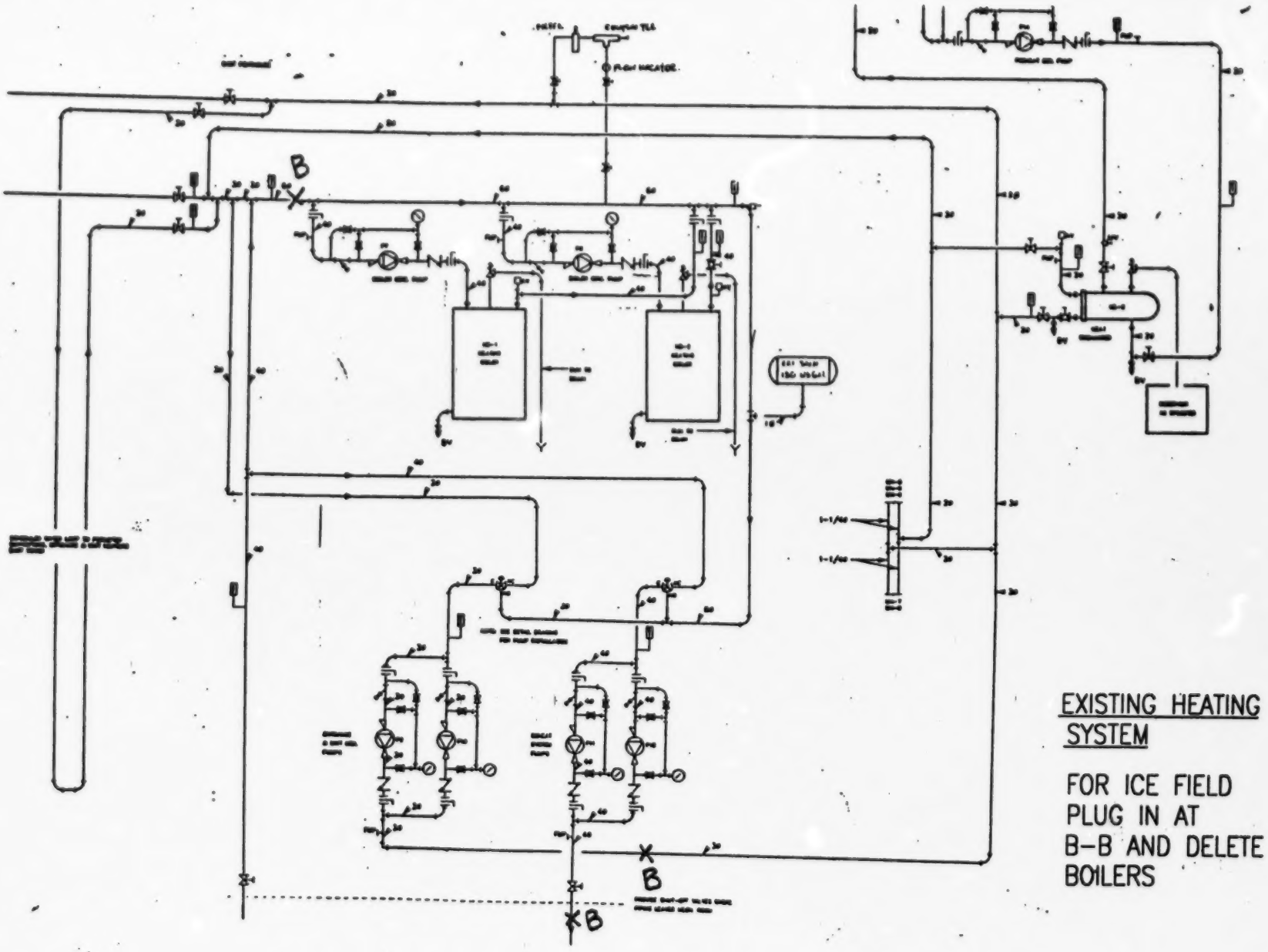
FIGURE 19



EXISTING COOLING SYSTEM

FOR ICE FIELD, PLUG IN AT A–A AND DELETE PIPING ON LEFT

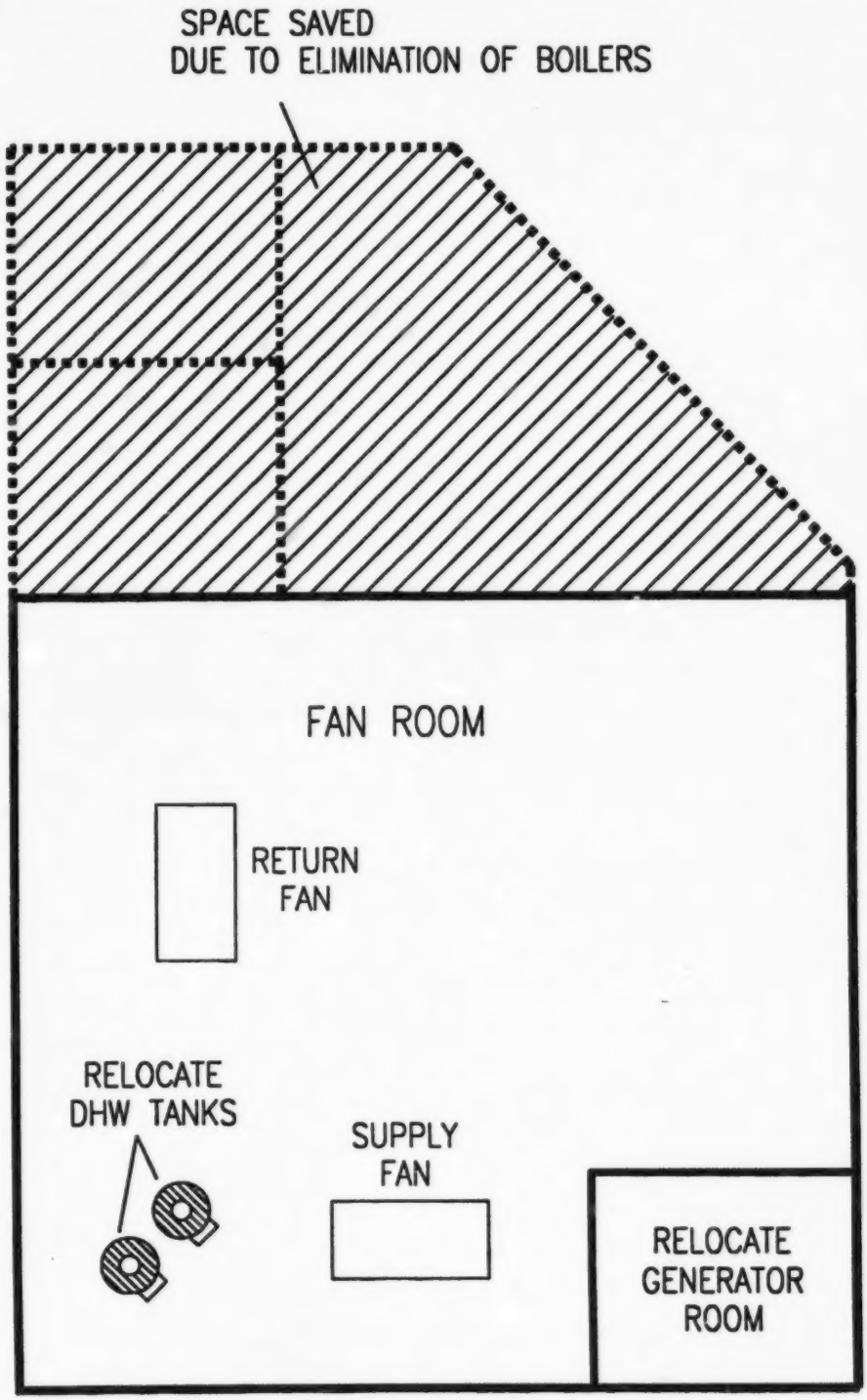
FIGURE 20



EXISTING HEATING SYSTEM

FOR ICE FIELD PLUG IN AT B–B AND DELETE BOILERS

FIGURE 21



SCALE
1"=12'

EAST PENTHOUSE

FIGURE 22

PARTIAL STORAGE CIRCUIT

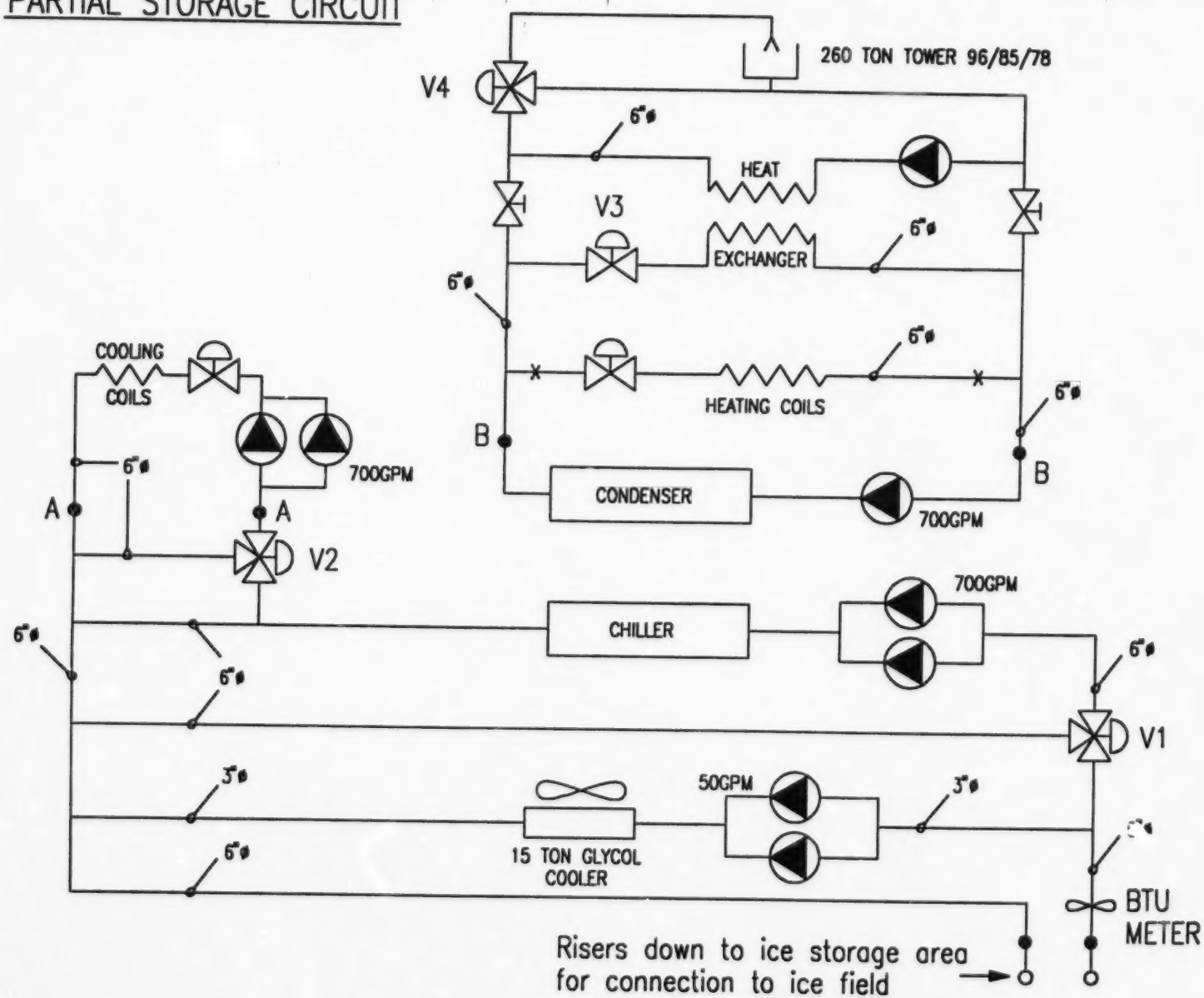


FIGURE 23

FIGURE 24

ICE FIELD COSTING

Item	FULL STORAGE			PARTIAL STORAGE		
	Bathtub $	Trenched $	Vertical $	Bathtub $	Trenched $	Vertical $
Excavation and soil replacement incl. tube laying						
@ $6/m^3	301,460			66,955		
@ $25.75/ft		428,309			127,591	
@ $6/ft			1,204,000			450,000
Concrete Header Trench incl. 2 in. insulation & electric heat @ $145/ft	41,830	39,585	33,350	15,360	12,253	20,300
6" insulated headers @ $60/ft of trench	17,309	16,380	13,800	6,356	5,070	8,400
Header Connections incl.valves						
1/2" @ $10	12,931			9,317		
2" @ $40		13,440	1,920		4,160	1,200
Drainage tile @ $1/ft	7,933	16,633	-	1,589	4,955	-
1/2 dia.tube @ $.10/ft	35,560	36,489	-	13,975	14,363	-
Subheader piping						
1" @ $.50/ft						
1 1/2" @ $2.00/ft	-	66,533	34,560	-	19,820	13,200

FIGURE 24

ICE FIELD COSTING

Item	FULL STORAGE			PARTIAL STORAGE		
	Bathtub $	Trenched $	Vertical $	Bathtub $	Trenched $	Vertical $
Takeoffs @ $10	-	16,800	3,220	-	9,360	1,960
12 in.layer pit run over field @ $6.50/$m^3$	17,958	20,022	14,907	4,415	5,964	5,444
SUB TOTAL	434,981	654,191	1,305,757	117,967	203,536	500,504
6" insulated piping from trench to building	18,000	18,000	18,000	18,000	18,000	18,000
3/4" water makeup to field and 4" drain	5,000	5,000	5,000	5,000	5,000	5,000
TOTALS	457,981	677,191	1,328,757	140,967	226,536	523,504

FIGURE 25

RELATIONSHIP OF HEAT PUMP TO PERCENTAGE OF ANNUAL COOLING LOAD SERVED WITH PARTIAL STORAGE

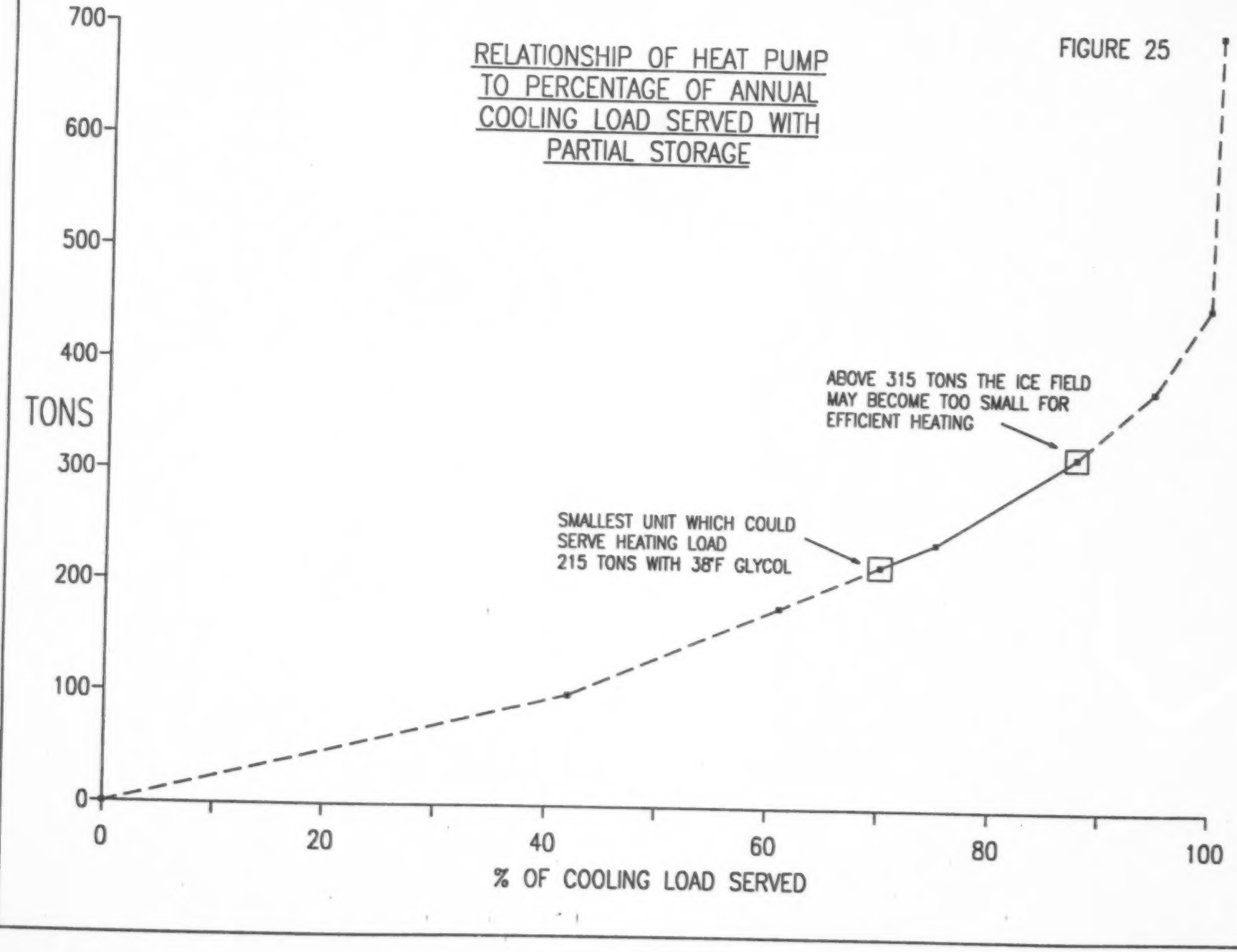
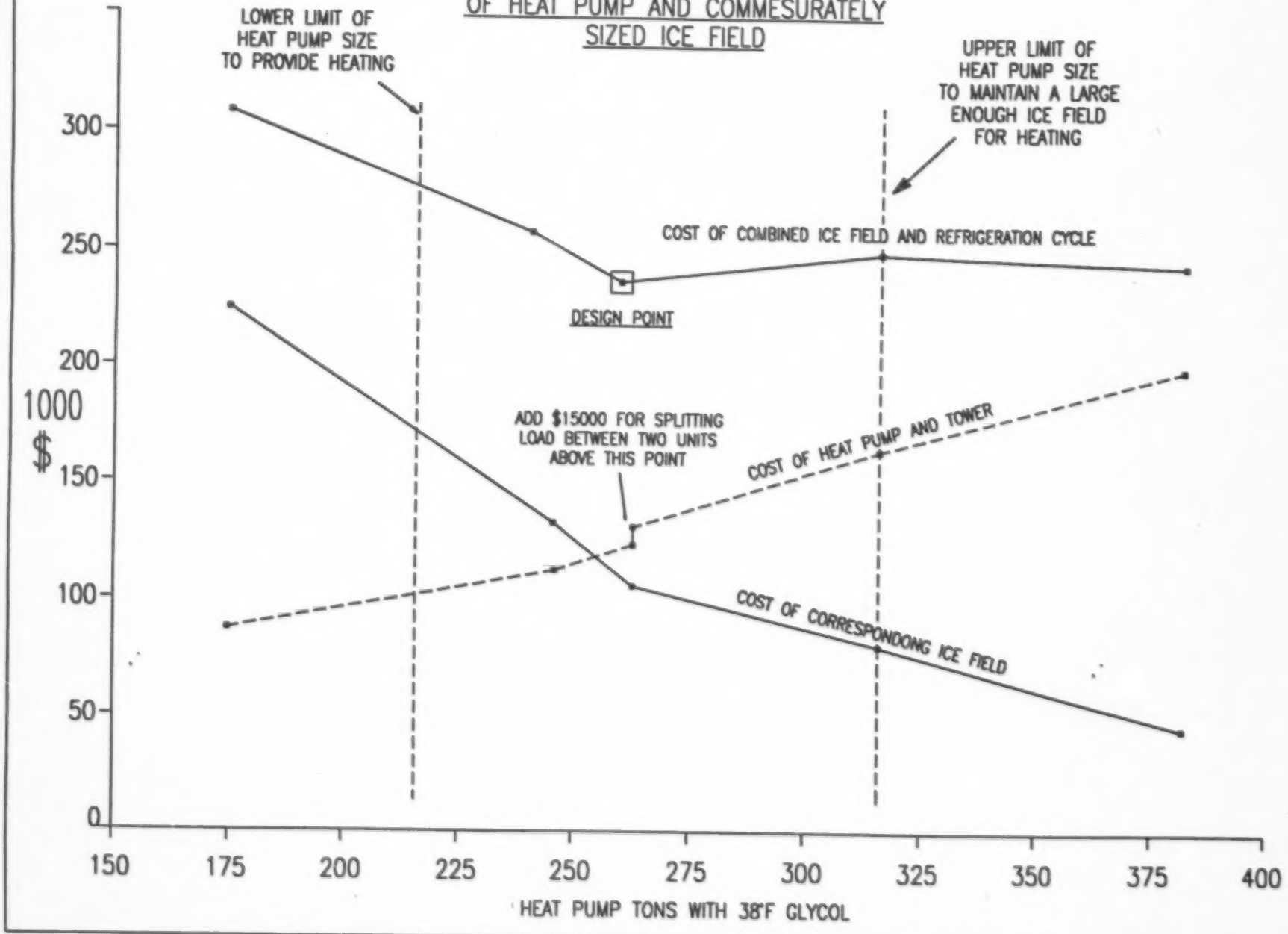
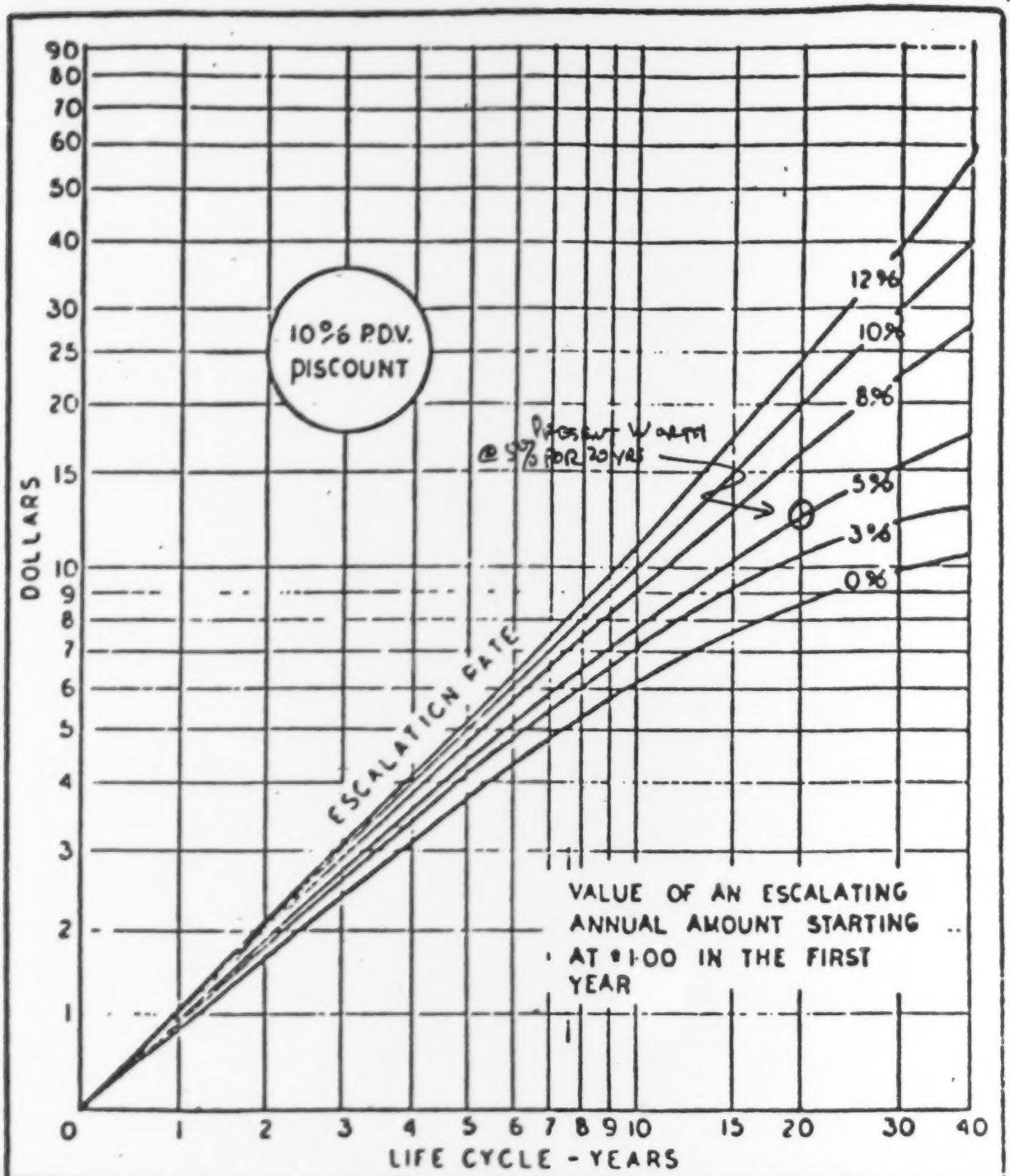


FIGURE 26

RELATIONSHIP OF RELATIVE COSTS OF HEAT PUMP AND COMMESURATELY SIZED ICE FIELD





R. T. TAMBLYN

ENGINEERING INTERFACE LTD.

TITLE: LIFE CYCLE COST

DATE: DEC'74

FIGURE 27